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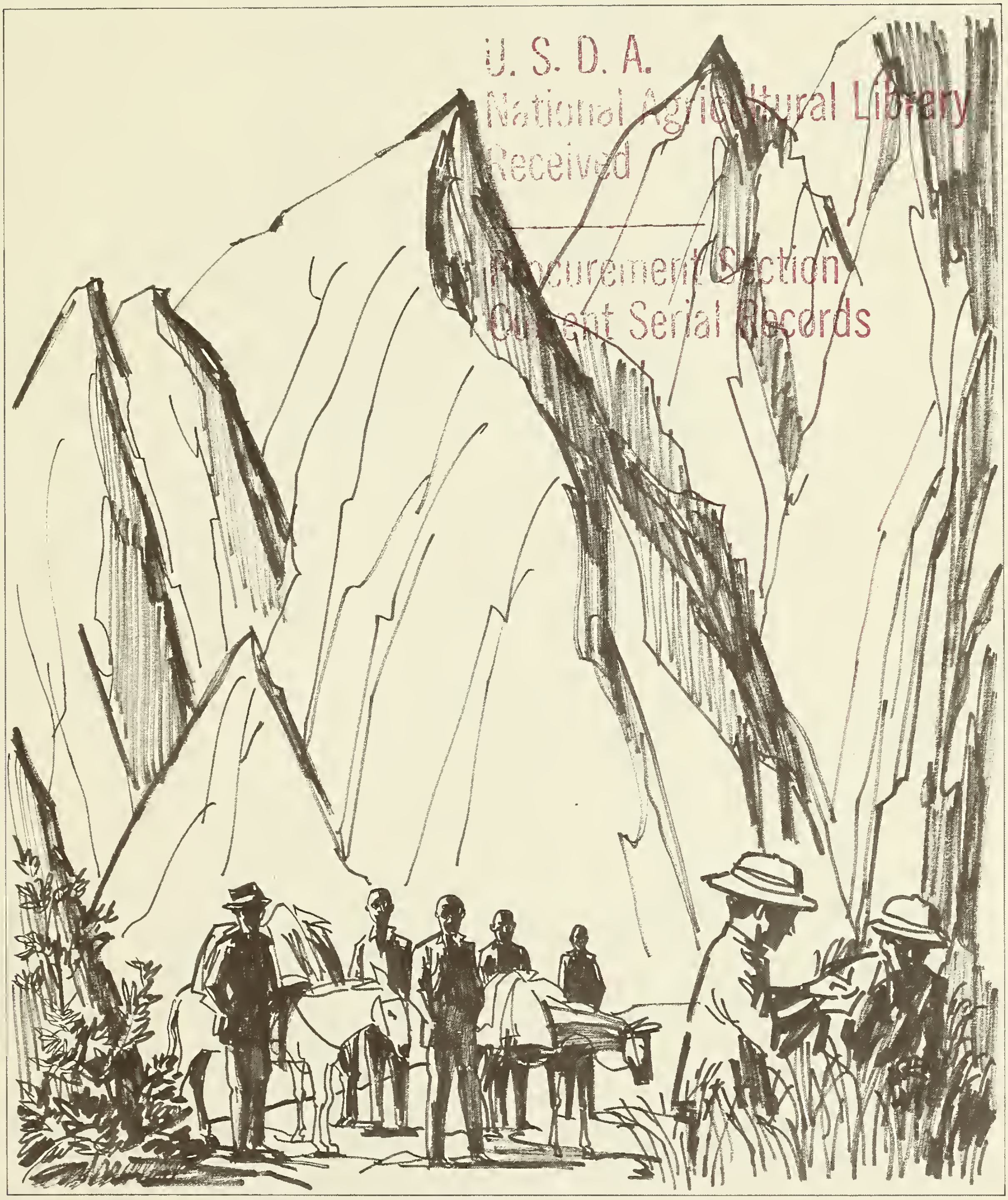

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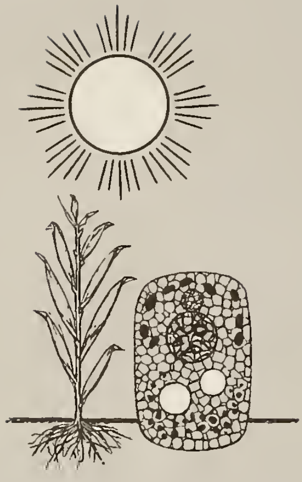

AGRICULTURAL SCIENCE REVIEW

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ROY L. LOVVORN, Administrator

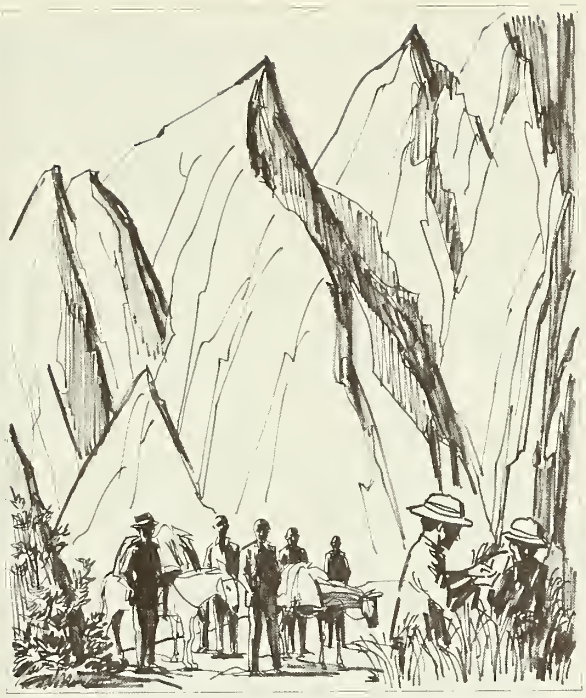
Man in the World

Historians tell us that man began to plant crops and till the soil about 10,000 years ago. That step—man learning to manipulate his environment—was the basis for civilization. It was the step that made it possible to feed and clothe populations that were to come.

To care for our now rapidly growing numbers, it is evident that we will for some time continue to manipulate and modify our environment. It is certain too that this can intensify the ecological and population imbalances that are being decried by so many, usually in a tone of desperation.

But there is ground to believe that we can solve our world-scale environmental problems. A few reasons: Our growing understanding of the interactive relationships of soil, plants, water, and animals and our determination to use this knowledge to maintain the biological web which makes life on earth possible. (For evidence of such work, see articles in the present issue of the *Review.*) Our increasing ability to make wastelands bloom and fertile lands even more fruitful. Our growing efforts to achieve a "wasteless world" in which materials will be cycled and recycled for agricultural and industrial use. Our continuing search for cheap energy which can mean cheap food, clothing, and housing. Our rising awareness of the need for population control at a time when methods and means are available for use in such an effort.

We have most if not all the knowledge we need to solve our environmental problems. What we lack is a better understanding of the role of science in human affairs. Such knowledge must be firmly woven into our education and politics. It must then be disseminated so that we—all mankind—can continue to do what we have done these thousands of years—exercise our power of choice, and more intelligently, we hope, than we have done in much of our past.—J.W.W.



GENETIC VULNERABILITY OF MAJOR CROPS:

A Challenge to Scientists and the Nation

"IN 1970 an epidemic disease swept swiftly over the corn crop of the United States. A great agricultural resource of the country was threatened. In some sense science and technology had been responsible."

So begins the report, "Genetic Vulnerability of Major Crops,"[1] prepared by a committee of the Agricultural Board, Division of Biology and Agriculture, National Research Council of the National Academy of Sciences.

The epidemic disease was the southern corn leaf blight[2] which caused the yield of corn to drop an estimated 50 percent or more in some Southern States and 15 percent nationwide.

Following the blight epidemic the Agricultural Board established a committee to look into the circumstances surrounding the epidemic and to examine the more general issue of whether the genetics of other major crops is such that they also are vulnerable. The study was supported by the Research Corporation of New York and the U.S. Department of Agriculture.

The report that emerged is divided into three sections: The first part examines the corn blight epidemic in detail, the second part deals with the genetic vulnerability of major crops, and the third part explores the challenges to science and to the Nation that are posed by genetic vulnerability.

Following, in its entirety, is that third part:

[1] Obtainable from the Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Ave. NW., Washington, D.C. 20418; 320 pages.

[2] See *Agricultural Science Review*, vol. 8, No. 4, 1970, p. 1.

THE CHALLENGES OF GENETIC VULNERABILITY

TWO points are clear: (a) vulnerability stems from genetic uniformity; and (b) some American crops are on this basis highly vulnerable. This disturbing uniformity is not due to chance alone. The forces that produced it are powerful and they are varied. They pose a severe dilemma for the sciences that society holds responsible for its agriculture. How can society have the uniformity it demands without the hazards of epidemics to the crops that an expanding population must have?

The severity of the dilemma will stimulate some intensive thought by the scientists and policymakers concerned. There will be shifts in philosophy, shifts in the allocation of present resources, and hopefully the allocation of additional resources.

How Uniform and How Vulnerable Are the Crops?

THE central question is how uniform and vulnerable are American crops? This is best answered by table 1, particularly in the last column, which shows the percentage of the acreage of each crop that is planted to a limited number of varieties. For example, 96 percent of the pea crop is planted to only two pea types and 95 percent of the peanut crop to nine varieties of peanut. The figures go as low as 25 percent for two varieties of wheat and 42 percent for two sugar beet hybrids. The data in table 1 have important implications for the Nation, the farmer, and the scientist.

In a certain sense the use of pesticides on crops also reflects genetic vulnerability. Pesticides are used on crops that have a high per acre value and for which pest resistance is inadequate. Farmers naturally prefer resistant crops, but they must use pesticides when the breeders are unable to provide them with resistant varieties. From an epidemiological standpoint the pesticide is used to provide an effect on the pest comparable to genetic resistance.

The extent of this reliance on pesticides is illustrated in table 2, which shows costs of using them for 1966. The relative difference in use of fungicides and insecticides reflected in table 2 may be attributed to a number of factors:

1. More effort has been expended on resistance to disease than to insects due to the greater difficulties in establishing uniform insect infestations.

2. There is greater availability of germ plasm conveying resistance to disease.

3. Cost per acre of treatment in relation to the value of the crop must be considered.

There has recently been, however, an increased emphasis on breeding for insect resistance.

Breeding for insect resistance and the development of other methods of control such as the use of hyperparasites (species parasitic on other parasites) take considerable time and effort. If the current trend to reduce drastically the use of insecticides continues there will be a vulnerable period before these other kinds of control are fully developed.

The striking uniformity among American crops is no accident. Strong forces have been exerted by the market and by farmers, to which plant breeders, plant pathologists, entomologists, and others have responded as well as they could in deriving the best compromises obtainable. That the Nation has experienced so few epidemics provides convincing evidence that their efforts have been remarkably effective.

Consumers and Processors Demand Uniformity

IN America it is axiomatic that the marketplace sets the priorities: "The customer is always right." For years no poultryman in his right mind would try to sell white eggs in Boston or brown eggs in New York. Similarly, no supermarket would display deep-eyed, expensive, but good quality Irish Cobbler potatoes when it can get handsome, shiny skinned, inexpensive, but soapy Red La Soda potatoes—housewives prefer the smooth skin. The same standard applies even to the pearls produced by Japanese oyster farmers; the market demands a smooth uniform pearl, and others are contemptuously called "baroques." The corn breeder must produce Dent corns in Iowa, but Flint corns in India. The lettuce breeder must produce a Great Lakes heading type, the pea breeder an Alaska or Perfection type, the snap bean breeder a Tendercrop or Blue Lake type, and so on.

Clearly the market wants uniformity. If one breeder or one farmer fails to provide it, the market

TABLE 1.—*Acreage and farm value of major U.S. crops and extent to which small numbers of varieties dominate crop acreage (1969 figures)*

Crop	Acreage (millions)	Value (millions of dollars)	Total varieties	Major varieties	Acreage (percent)
Bean, dry	1. 4	143	25	2	60
Bean, snap	0. 3	99	70	3	76
Cotton	11. 2	1, 200	50	3	53
Corn [a]	66. 3	5, 200	[b] 197	6	71
Millet	2. 0	?		3	100
Peanut	1. 4	312	15	9	95
Peas	0. 4	80	50	2	96
Potato	1. 4	616	82	4	72
Rice	1. 8	449	14	4	65
Sorghum	16. 8	795	?	?	?
Soybean	42. 4	2, 500	62	6	56
Sugar beet	1. 4	367	16	2	42
Sweetpotato	0. 13	63	48	1	69
Wheat	44. 3	1, 800	269	9	50

[a] Corn includes seeds, forage, and silage.
[b] Released public inbreds only.

TABLE 2.—*U.S. expenditures on fungicides and insecticides, by crop (1966)*

Crop	Fungicides				Insecticides			
	Acres treated (1,000)	Cost/ acre	Total ($1,000)	Percent of farm value	Acres treated (1,000)	Cost/ acre	Total ($1,000)	Percent of farm value
Corn	[a] 0	0	38	0	21, 804	1. 81	39, 589	0. 8
Wheat	0	0	0	0	1, 090	. 78	850	. 1
Sorghum	0	0	0	0	329	3. 29	1, 082	1. 6
Rice	0	0	0	0	198	1. 63	322	. 1
Potato	359	10. 47	3, 758	. 6	1, 332	5. 56	7, 405	1. 2
Sugarbeet	122	9. 43	1, 150	. 4	147	2. 15	316	. 1
Vegetables	738	5. 35	4, 081	. 2	2, 066	8. 49	17, 540	1. 1
Soybean	0	0	54	. 1	1, 496	1. 83	2, 737	. 1
Cotton	207	7. 60	1, 573	. 1	5, 588	10. 30	57, 556	4. 6
Total			68, 460				131, 629	

Source: Austin S. Fox, Economic Research Service, USDA.
[a] Less than 0.5 percent of acres grown.

will turn to another that will. The irony is that if the uniformity encourages an epidemic, the scientist, not the market, tends to receive the blame.

The market is just as insistent on cost as on uniformity. The market wants to pay the lowest price. If one farmer cannot sell it for the price, another will.

In the sense that the market demands uniformity and low costs, it transfers to the farmer the responsibility for demanding uniformity in turn. In order to meet the cost-price squeeze, the farmer first seeks to raise his efficiency per acre and above all per man-hour.

Demands for efficiency are really demands for uniformity in a different guise. The farmer must have high-yielding varieties. Because the low-yielding members of the plant population have been eliminated, this too means uniformity. The farmer must substitute machines for men, but machines can't think; again varieties must be uniform.

Seeds are sown by machine. These too must be uniform or they move unevenly and inefficiently through the planter. The seeds must germinate and grow simultaneously, or they leave space for weeds to grow in the row where the cultivating machine cannot go.

Crops must be uniform for harvesting. Tomatoes, peas, and potatoes must ripen at the same time if they are to be machine harvested, because the machine cannot distinguish between a green tomato and a ripe one.

And so it goes, uniformity—always uniformity.

Genetic Nature of the Uniformity

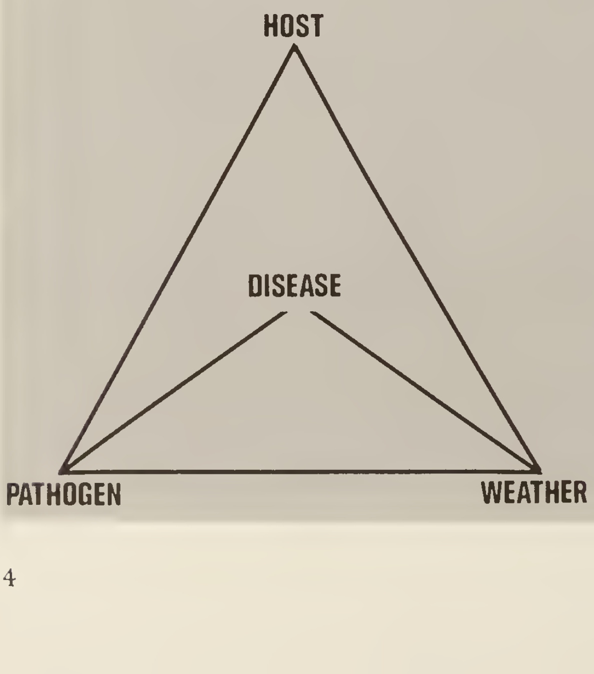
GENETIC uniformity can take many forms. In the case of vegetatively propagated plants, each variety is uniform for all genes except as mutations occur. If one plant is susceptible, they all are. Apples, for example, are vegetatively propagated; without protective chemicals most apple varieties would be subject to an epidemic of apple scab or apple maggot every year.

Such self-pollinated plants as wheat or bean are similar to vegetatively propagated plants in that varieties are much more uniform than outbreeders. This was the case of the Victoria oat that succumbed to the *Helminthosporium* epidemic, the Marquis wheat that went down before a new race of rust, and the Refugee bean that had to be abandoned because of the common mosaic disease.

Corn is an open-pollinated plant and without man's intervention would be genetically diverse. Breeders reduce it to pure lines, however, by inbreeding—the equivalent of self-pollination.

Uniformity need not rest on a single variety, however. It can rest on a single gene or a single cytoplasm, as in the instance of the Texas male-sterile

THE DISEASE TRIANGLE



TO understand what causes epidemics it is necessary to understand the nature of plant disease. Considering only a single plant, there are always three factors that must come together in space and time in order for a disease to occur:

- The host—a susceptible host, of course.
- The parasite—a virulent, aggressive parasite that can readily gain entry into plant tissues, colonize them quickly, and reproduce (sporulate) abundantly.
- The environment—a favorable environment. Under the term "environment" a number of factors are included—rain, dew, relative humidity, temperature, wind, soil type, nutrition, light. For our purposes however, environment can be virtually equated with weather.

cytoplasm. Uniformity of this kind has now been introduced into commercial varieties of sorghum, millet, sugarbeet, and onion, and it could well become important in wheat. Cytoplasmic uniformity is also found in cotton and cantaloupe.

The important question therefore arises: Does cytoplasmic male sterility aggravate disease in any of these? The answer is "yes." The male-sterile wheats grown thus far in research plots in the United States are especially susceptible to ergot. In India male-sterile sorghum also has shown appreciable susceptibility to ergot. The problem in both wheat and sorghum seems to stem from the fact that the female plants have open florets as a result of inadequate pollination and is confined to seed production fields. These situations must be closely watched.

A given technological advance in crop production often rests on small numbers of genes. Prominent examples are the dwarf wheats and the single-gene dwarfism in the rice varieties that comprise much of the base for the "Green Revolution." Other examples are the monogerm sugarbeets, the determinate gene of tomato, and the stringless gene in beans.

If one of these genes is incorporated into many varieties, the crop becomes correspondingly uniform for that gene. If a parasite with a preference for the characters controlled by that gene were then to come along, the stage would be set for an epidemic, which is precisely what happened when the determinate tomato was introduced in the early 1940's. Varieties with that gene were very susceptible to *Alternaria solani* until new genes for resistance could be incorporated.

Wheats with the dwarf gene are showing susceptibility to the fungus *Alternaria triticina* in the Punjab in India. Dwarf wheats in Mexico are also unusually susceptible to the leaf blotch caused by *Rhyncosporium* sp. This is not to say, of course, that they are uniform in other characters—indeed, they certainly are not. But many wheat varieties do contain the dwarf gene, just as many corn varieties contained Texas cytoplasm. In 1970 the corn varieties in use were diverse for many characters but they were uniform for the T-cytoplasm character. For a major epidemic to take place the crop need be uniform for only one character, *provided only that the character in question is favorable to the disease.*

Of course, other genes can influence the single gene or the single cytoplasm, as is evidenced in corn. If they exert enough influences, they may thus aid in quelling an epidemic.

While uniformity is a prerequisite to vulnerability, uniformity alone cannot produce epidemics. But when a parasite appears that can exploit the gene or cytoplasm that brings about uniformity, then the uniformity provides a situation in which an epidemic can occur.

Government Encourages Uniformity

In pursuing uniformity, the farmer is encouraged by State and Federal seed agencies, who, for decades, have emphasized the importance of uniformity and purity. The entire seed certification program, for example, has adversely influenced genetic diversity through its efforts in this direction.

The law not infrequently outruns biology; thus Federal regulations in Canada designed to promote uniform wheat quality impose stringent require-

Genes from primitive Coroico corn (left), which grows in the Andes Mountains, may be used to improve U.S. commercial hybrids like the ear shown with it.

ments on development of new wheat varieties in that country. The indirect effect of this legislation has been to narrow the germ plasm base and increase potential vulnerability of Canadian wheat. A similar effect has developed from the enforcement of a one-variety cotton law in the San Joaquin Valley of California and, more generally, from the recently enacted Federal plant variety protection law.

CHALLENGES TO THE SCIENTISTS

EVENTUALLY the challenge of genetic vulnerability winds up on the desk, and in the greenhouses and field plots, of the scientists.

Public Support for Research in Plant Breeding

SUPPORT for research falls into several categories. If new varieties have sufficient income potential to an individual firm to justify a breeding program, private capital will support a significant amount of the work. Otherwise, the responsibility is usually left to the public agencies. The relationship between State and Federal responsibility for plant breeding is quite analogous to the relationship between industry and public agencies; if the benefits accrue uniquely to an individual State, the State is often willing to support the cost of research. But if not, Federal support is sought. No one system neatly fits every situation. Industry, State, and Federal agencies all tend to share the expense of long-term breeding programs. The proportion of cost borne is the end result of political negotation. In fact, one of the basic arguments put forth in support of varietal patent protection (Public Law 91–577) was that income derived from royalties or licensing would encourage greater participation by private industry in plant-breeding research.

The priorities set by public agencies for research support must recognize the different needs for a wide spectrum of crops. Vegetable crops must compete with agronomic and forest crops, though the total dollar value of vegetables is usually secondary to crops grown over extensive acreages. (Support for research in plant breeding is listed in table 3.) It is difficult to determine the minimum number of professional people necessary to insure that the interests of the public are protected. Obviously 65.1 scientific man-years committed to corn breeding by public agencies, plus an even larger commitment in the private industries, were inadequate to prevent the losses resulting from southern corn leaf blight. As the number of individuals committed to breeding decreases, the amount of germ plasm actively used by breeders also decreases. Much potential germ plasm is lost for lack of manpower and an inordinate amount of public responsibility must be assumed by a few individuals. The degree to which these few can effectively create, evaluate, release, and store valuable germ plasm is extremely limited.

In this context, the breeder seldom wins. If he appeals his case to the public, he is labeled a public relations man who should spend more time in the laboratory; if genetic vulnerability results directly from his research efforts, he is labeled shortsighted with respect to the limitations of new germ plasm or insensitive to his public responsibility. As a result, the plant breeders in the public sector do what they can within the limits of their support. If they have a source of disease resistance they use it; to develop backup systems is a luxury they cannot often afford. For the most part, other breeding problems are accorded a higher priority. It is hardly surprising that in 1969 over 50 percent of the plant-breeding work in public institutions was directed to yield (25 percent) and disease and insect resistance (28 percent), while as little as 8 percent was expended on quality factors and 2 percent on physiological and morphological research. These priorities result largely from the demands of industry and the limitation of research resources.

The scientists challenged by the issue of genetic uniformity are not only plant breeders—they are joined by agronomists, biochemists, geneticists, climatologists, economists, entomologists, plant pathologists and plant physiologists. All, but especially the plant breeder, the plant pathologist, and the entomologist, find themselves under a frustrating pressure. Each hopes to serve society well, but society wants uniformity. The scientist provides it, knowing full well that one day his uniform variety may suffer in the face of an epidemic.

Collectively, plant breeders have a most important influence on the amount of genetic uniformity to be found in commercial crop varieties. What, therefore, might the breeder be expected to do to reduce genetic vulnerability of the crops with which he works?

Procedures used by most breeders tend to narrow

TABLE 3.—*Scientific man-years (SMY) assigned to plant breeding research (1969–70)*

Commodity agronomic	Total (SMY)	Commodity horticultural	Total (SMY)
Corn	65.1	Potato	20.2
Grain sorghum	16.4	Carrot	1.5
Rice	7.5	Tomato	20.8
Wheat	51.2	Bean pea	20.1
Barley	20.0	Sweet corn	3.3
Oats	15.2	Cucurbit	10.5
Small grains	[a] 23.3	Sweetpotato	3.7
Soybean	35.9	Crucifer	1.2
Cotton	45.8	Onion	1.0
Tobacco	32.3	Vegetable crops	[b] 35.1
Alfalfa and other legumes	24.3		
Grasses and other forages	33.0		
Total	370.0	Total	117.4

Source: Analysis of 1969 CRIS reports by H. J. Hodgson, Cooperative State Research Service, USDA.

[a] Scientific man-years assigned to small grains without specifying crop. This value is in addition to the assigned values for wheat, barley, and oats.

[b] Includes lettuce and other crops not itemized separately; in addition this value would include commitment to the listed vegetables without specifically designating the programs by crop.

rather than expand the genetic base of cultivated plants. The most efficient systems of developing improved varieties involve the use of proven, elite germ plasm rather than unadapted "exotic" varieties. Thus, the tendency is to extract new genetic recombinants from crosses of the best germ plasm to be found in widely used commercial varieties and hybrids.

The concerted use of elite sources of germ plasm in no sense takes place because other more diverse sources are unavailable. On the contrary, for most important corps, a vast array of genetically diverse germ plasm is available. Such material, however, is difficult to work with because it is untested and poorly adapted. Consequently, the breeder who is expected to produce positive results within reasonable periods of time naturally chooses to work primarily with the newer, more elite, and best adapted materials. He may feel he cannot afford the time and effort required to screen scores of collections in the hope of finding a few useful genes.

Both public and private scientists have two principal responsibilities in reducing vulnerability. First, they must exercise constant viligance in detecting new hazards. Second, they must expand and refine their resources for combating disease by providing new parental material. An excess as well as diversity in breeding stocks is the surest measure. In addition the scientists must push forward in their understanding of the basic principles of parasitism. To make maximum use of field resistance they must understand the life history and ecology of the parasite. Lastly, they should strive to elucidate the pathway between genes and the specific attributes of resistance. Only when this last is done can we move to more exact and specific measures of combining epidemics.

Freedom from epidemics is purchased at the price of vigilance. Though U.S. corn breeders tested their Texas cytoplasm against *Helminthosporium*

maydis at several locations, they did not test their material against the Philippine fungus. They concluded that in the Philippines, it was the weather, not the parasite, that differed from that in the Corn Belt.

To disperse a uniform variety of whatever type or whatever crop over much of the country is to spread a wide net. If a parasite has mutated anywhere it will be caught. Hence, even a trace of infection, anywhere, should be examined with great care.

Tunnel Vision

SCIENTIFIC tunnel vision may have obscured somewhat the significance for corn of the oat epidemic and of the phenomenon of drug resistance. The Texas male-sterile corn was deployed over a wide area, as was DDT against flies, with similar consequences: a new strain of *H. maydis* overcame the Texas strain of corn in the same way that a new strain of houseflies overcame DDT.

Exotic Pests

MOST, if not all, of the epidemics discussed in this report have been generated by exotic pests. The parasites that attacked French grapes came from North America. Chestnut blight and Dutch elm disease came originally from the Orient, as did the Japanese beetle. The potato blight fungus doubtless came from Central or South America, the boll weevil, from Mexico. The Hessian fly moved across the Atlantic with the straw brought along to feed and bed down the horses used by Hessian soldiers in the Revolution.

The list is endless, the message clear. Man generates his own epidemics because he carries his parasites along with him. Not all the possible parasites have yet been brought to the United States. Some are serious problems abroad on the very crops we grow here at home. The Nation has done little to test domestic varieties of crops against the exotic pests not yet arrived. The corn blight is a case in point. American strains of corn could have been taken to the Philippines and tested against the Philippine strain of the fungus as early as 1964.

Backup Capability—Diversity of Genes

IF uniformity be the crux of genetic vulnerability, then diversity is the best insurance against it. Since the market demands uniformity, the challenge to the breeder is to provide diversity. He must build redundancy into a backup system.

As for the corn blight epidemic, it must be recognized that breeders, both commercial and noncommercial, did have a highly effective backup system. When some small defects appeared in the T-cytoplasm system, they began to put normal cytoplasm

At the national "seed bank" a test tray is taken from the walk-in germination chamber where seeds are tested before storage and every 5 years thereafter.

back into hybrid seed production. This program was pushed strenuously during the winter of 1970–71, when seed from normal cytoplasm was grown in Mexico, Hawaii, Argentina, and other areas. A major proportion of the seed produced in 1971 for the 1972 crop was produced from inbreds with normal cytoplasm.

Sources of Genes for Diversity

THE breeders have met the challenge to offset uniformity with diversity by searching for new genes and by developing gene pools to preserve those they have.

Wild Types and Varieties. In the case of a few crop plants, the breeder can go back to the geographic area where the crop seems to have originated in a search for useful genes from the wild types occurring there or even from varieties that local farmers grow. This requires trips of exploration, of course.

The primitive varieties and wild types are threatened, however, by the invasion of their homeland by "improved" varieties. These latter have lost many genes in the process of tailoring them to the uniformity required by the sophisticated markets. Nobody can yet assess the magnitude of this threat.

Several bodies have investigated the extent of this genetic erosion: in 1967 the International Biological Program (IBP) sponsored an international discussion in Rome (Frankel and Bennet, 1970), and FAO is also cataloging existing germ plasm collections of major crops throughout the world.

Local Varieties. Scattered over the globe are innumerable varieties adapted to local conditions. These can be collected and serve as a source of miscellaneous genes for disease resistance or other attributes.

Spontaneous Mutations. The Texas strain of *Helminthosporium maydis* dramatically illustrates the truism that organisms mutate. Most crop plant mutants are offtypes and farmers rarely save them. Occasionally one does, as in 1922 when a farmer in Enfield, Conn., observed an ear of corn in his field that had a peculiar look—it was opaque, not translucent. Knowing that Singleton and Jones at New Haven were saving peculiar corn types, he sent it to them. They named it Opaque–2 and held it in their gene pool for 40 years. Mertz and Nelson, at Purdue University, found it to be the source of a gene for high lysine, and therefore of significant potential for improving the nutritive value of corn.

Induced Mutations. Man can empirically induce an occasional useful mutation by treating plant parts with ultraviolet radiation, X-rays, gamma rays, or with chemical mutagens.

Wise Use of Resistance

IN the past each new gene for resistance has been pressed into service with little thought of the probable side effects. The analogy between the uses of crop plant resistance in agriculture and the use of antibiotics in human medicine is pertinent here. The appearance of bacteria resistant to penicillin brought about not only a search for new antibiotics but led eventually to restraint in their use. Doctors realized the dangers of squandering antibiotics by using them in trival ways that allow resistant pathogens to develop. Antibiotics are now available only on prescription.

The plant breeder recognizes the dangers inherent in single-gene resistance. However, until general resistance is found or developed, public pressure requires that he release any type of resistance available that will minimize a current threat even though the longer term hazards remain. There are instances where specific resistance is extremely valuable but endangered by its geographical deployment. Each year oat crown rust sweeps north, blown by prevailing winds from areas where the spores survive the winter. The resistance genes used to control the rust in the South should be different from those used in the North where the disease will finish its course. If they are the same the buildup of virulent races in the South could lead to heavy infestation elsewhere. Achieving wise deployment necessitates widespread agreements that may sometimes transcend local short-term interests. Breeders and pathologists must prescribe wisely to shepherd our resources of resistance and maximize their usefulness.

Preserving Genes for Diversity

AN effective device being used more and more by geneticists and plant breeders to meet the challenge of uniformity is the germ plasm bank or gene pool. The genes preserved there are to be drawn upon when needed; they provide the base for diversity. Gene pools have generally been developed by the breeders themselves and, hence, are widely scattered. This in itself is diversity of a sort, but it has

a serious built-in hazard—if a breeder dies or retires, his material may well be lost.

CHALLENGES TO THE NATION

THE Nation cannot tolerate epidemics of disease or insects in its basic food and fiber crops. Thus it must face up to the threat posed by such epidemics.

A Watchdog System

ONE measure to meet the challenge of ignorance is to set up a watchdog system with several components; some of these are already in existence, others must be established.

Overseas Laboratories. Clearly, a study of exotic pests that are potential threats to our major crops should be considered. In 1966 a plant sciences panel appointed by the National Academy of Sciences emphasized this point, saying:

> Some diseases are of little consequence in their homeland abroad, but they can be devastating when they emigrate to the United States * * * Facilities are, therefore, needed to study diseases and insects abroad, using American varieties and clones planted where they can show their resistance (or susceptibility) to diseases endemic in Europe, Asia, or Africa.

Specifically, such crops as corn, cotton, sorghum, and millets should be tested against insects and parasites at breeding stations in the tropics where those crops originated.

The varieties should be tested where the exotic pests are, not after they are imported. Yet only a very small amount of work was done in this direction as Public Law 480 funds became available. Most of these funds have now dried up in those countries where our basic food crops originated. As a substitute, such work could be easily established in cooperation with local experiment stations.

Offshore Laboratories. Offshore laboratories to study susceptibility of American crops to exotic pests would be useful. The USDA already operates some facilities of this kind; the Plum Island Animal Disease Laboratory in Long Island Sound was established to investigate the hoof-and-mouth disease of cattle, and the facilities of Mayaguez, P.R., are being utilized to screen wheat and oats against exotic races of rust. The Committee feels that much more of this sort of testing should be done to assess the vulnerability of our crops to exotic pests.

Quarantine Services. As any tourist can testify, the United States has an effective quarantine service to intercept pests at the borders. This is, in fact, the very last opportunity to stop them.

Agricultural Research Talent

IF an exotic pest is not studied on United States varieties abroad or in an offshore laboratory, and is not intercepted at the borders, it is very likely to be found quickly by an agricultural scientist at a State or Federal experiment station. By that time it will be too late to stop it completely, but at least the alert can be sounded and the situation dealt with.

Also important is the amount of effort that can be allocated to research and development designed more clearly to resolve unanswered questions. At present, genetic reserves of some crops are being mined because public commitment of personnel is insufficient to retain reasonable germ plasm resources.

A National Monitoring Committee

FINALLY the Committee suggests the establishment of a national monitoring committee to keep a watchful eye on the development and production of major crops and to remain alert to potential hazards associated with new or widespread agricultural practices. This would be, in effect, a committee for technological assessment. It could best serve under the auspices of a nationally recognized organization, and should be comprised of scientists from the USDA, the State experiment stations, the universities, industry, and the general public. It should be advisory in nature, but should be free to issue warnings wherever and whenever it feels them justified.

Germ Plasm Resources

EVERY introduction of variability to combat vulnerability depends on germ plasm resources. These are the raw materials that will be reshaped and fashioned through breeding to produce the crop varieties of the future. They are among our most precious commodities. Their wise and effective management is a vital task.

Many breeders and geneticists maintain their own gene pools, and thus have preserved innumerable genes from being lost. While the United States has

no native major germ plasm, its capacity to respond to threats of epidemic pests and diseases rests on the availability of suitable germ plasm. We must face the question whether the national effort is sufficient to meet the need.

Plant Introduction. The benefits of introducing new materials from the centers of origin are widely recognized. All plant breeders recognize the need for germ plasm banks in which representative samples of primitive races and their wild relatives, "land races," obsolete varieties, etc., are stored. Other than spontaneous mutations or those induced experimentally, the genes available in a germ plasm bank are the only primary resource for the plant breeder. Without them he is restricted to making recombinations of the genes already available in his breeding plots. Though the numbers of possible recombinations are enormous they can be lost rapidly as a single variety becomes predominant. Thus, while the need for germ plasm banks is obvious, the means of maintaining them efficiently deserves examination. The maintenance of living collections is extremely expensive and time consuming, yet not more so than the long-term, cumulative efforts expended by the plant collectors. Furthermore material collected even as recently as 10 years ago may no longer be available today. According to Frankel we may be approaching a situation where the primitive races of some of our crop plants will exist solely in germ plasm banks—they can no longer be collected in the wild. What is lost now may well be lost forever.

In the United States, the Plant Introduction Service of the USDA has met this challenge well within the resources available to it (Burgess, 1971). It organizes collecting expeditions in various parts of the world in response to the needs of private and public plant breeders and other plant scientists. The introductions are cataloged, screened for viruses and other parasites, and eventually made available to cooperating scientists through the regional plant introduction stations. Four such centers serve the continental United States; each has special responsibilities, for example, in maintaining and evaluating comprehensive collections or germ plasm banks of one or more crops. These programs have been, and

A USDA plant explorer and a Nepalese Government official examine a stand of bamboo in Nepal while searching for new plant species of value in improving and safeguarding U.S. agriculture.

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are now, very useful. Indeed many successful breeding programs began with materials received through the Plant Introduction Service.

Seed Storage Facilities. The National Seed Storage Laboratory, Fort Collins, Colo., maintains collections of seed under storage conditions that minimize deterioration and maintenance costs. These collections include seed of older primitive varieties that are no longer in cultivation.

The combined expenditure by the Agricultural Research Service and the States on the nationally coordinated plant introduction program is of the order of $2.6 million per year.

Long-term seed storage has several advantages. With low-temperature storage facilities and adequate monitoring it may be possible to maintain seed viability for at least 20 years. Consequently it is entirely possible to maintain germ plasm banks of many crop plants as seeds, and avoid the risks and costs of growing thousands of plant collections every few years.

As useful as cold-storage facilities undoubtedly are, they may engender an unwarranted sense of complacency. Once seed samples are carefully selected and stored away, the generation that deposited them is apt to turn to other matters—the responsibility of taking the stocks out of storage, of deciding where to grow them, and what to keep, is left to the next generation. Since stocks maintained solely in cold storage are not available for study and experiment, the next generation may well have had no first-hand experience whatever with the material it finds itself called upon to evaluate. Then, too, problems and breeding techniques change with time, and material that seemed useful in the 1960's may seem 20 years later to have been curiously chosen. There will be a temptation to discard those stocks that are not "relevant" at the later date. Yet what is discarded in the 1980's may well again be relevant in the year 2000. It seems, therefore, that study and evaluation must be a continuous process—both for the well-being of a collection and for the continued awareness of those for whom it is being maintained. One needs not only a "safe deposit" (cold storage) but also a "checking account" (living collection).

The maintenance of a living collection is usually regarded as a routine and time consuming, yet essential, task. Much of the material maintained there seems to be of little current interest—occasionally, of course, a threatened epidemic or new insight into a disease problem will generate a sporadic interest in screening everything available. A great deal of the material that leaves the bank is discarded; it is regarded as a gift, not as a loan. Surely a more suitable arrangement could be devised. One possibility is the development of germ plasm maintenance centers, in which maintenance is regarded as the primary goal, not as a byproduct of breeding activities. In this connection it is worth noting that the plant breeder, entomologist, or plant pathologist tends to regard a germ plasm collection as an inexhaustible source from which he can extract only such experimental material as is of interest for his specific purposes. On the contrary, the experimental taxonomist, crop plant evolutionist, and ethnobotanist consider the entire collection to be necessary experimental material—quite apart from its potential economic value. They need to preserve and study as wide a variety of material as they can manage and to use it continuously. Because all classifications have to be revised as new material is collected and new analytical procedures developed, the experimental taxonomist's work is never done. A germ plasm maintenance center could effectively serve a dual purpose as experimental material for several disciplines and as a reliable and continuing source of germ plasm for the plant breeder. Coupling these two objectives could relieve the plant breeder of a routine chore and provide the taxonomist and others with facilities and experimental material not now available to them.

The problem of organizing germ plasm maintenance centers varies considerably according to the crop. It is probably more straightforward in those plants that are ordinarily self-fertilizing annuals, like wheat and soybeans. The complexity increases when outbreeding plants (like corn) or plants that are perennial and winter-day (short-day) flowering are considered. Cotton combines all these disadvantages and a living collection of cotton germ plasm could only be established in a subtropical, frost-free environment. Since many of our crop plants are native to the subtropics, the establishment of a subtropical center should be carefully considered.

Variety Development

It would be foolish to think of the Nation's gene

pools as warehouses stocked with finished products. They are much more like stores of outdated military surplus equipment awaiting disassembly and reassembly into new, more useful forms. The items in a gene pool cannot be stored as disassembled parts but only within a living organism whose constituent properties are catalogued. These plant materials are exotic. They are usually unadapted to local conditions and well below the standard requirements for economic use. The development of a new variety that incorporates a new gene for resistance from such a pool takes time. For most crops this is hardly less than 5 years and for some might be longer than 20 years.

The search for genes for resistance and their incorporation in new varieties is a continuous process for many crops. For example, a cereal breeder who releases a new rust resistant variety may well have others in different stages of development that will be replacements for the years ahead. Meeting the challenge of an unanticipated threat exposes the weakness of the means whereby we hold the line during the interim period of varietal development. There is no simple solution. This weakness makes it all the more imperative to avoid genetic vulnerability in every way we can.

Collections of Parasites

GREEN plant germ plasm is of first importance, but the Nation must also have collections of fungi, bacteria, viruses, nematodes, and insects. The American Type Culture Collection, a nonprofit organization supported by Federal and other grants and the fees it collects for services, plays an important role in maintaining cultures of many of these parasites. Such other collections as that of the USDA Northern Regional Research Laboratory at Peoria, Ill., share this burden. There are no major collections of cultures of plant-destroying insects. While many species can now be reared in the laboratory there is only an incomplete index to existing individual collections in the United States. The increasing interest in crop resistance to insects will surely create a demand for cultures of insect pests in the future.

Mitigation of Loss

FINALLY, there are economic devices that the Nation may use to mitigate the impact of losses from an epidemic. The corn blight epidemic could have been disastrous had we depended more completely on corn, as did the preColumbian Indians. The T-strain of *Helminthosporium maydis* and a monoculture of T-cytoplasm would have been disastrous to their society, even though it was not disastrous to ours. The corn the Nation had already in storage dampened the economic impact of the epidemic, a circumstance that supports the principle of the "ever-normal granary." Moreover, unused acreage was available and could be diverted to corn the next year to restock the storage bins.

Crop insurance against the hazards of an epidemic is also available to individual farmers in the United States.

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COMMITTEE ON GENETIC VULNERABILITY OF MAJOR CROPS

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NEW ENERGY SOURCES FOR AGRICULTURE

It has been our habit as plant scientists and instructors in agriculture to emphasize contemporary photosynthesis as the basic transformer of solar energy to food energy to the exclusion of other essential energy inputs. We need not apologize for having thought this way in the past, but the time has come for serious understanding of the role that fossil fuels have played in the great success story of America's agricultural productivity. As agriculturists, we must begin to assume active roles in earmarking nonfarm energy resources for future agricultural use because modern agriculture has become thoroughly dependent upon the availability of nonrenewable fossil fuels. We have reached a point in time when the food reaching the tables of American citizens costs as much or more in fossil-fuel energy than is represented in the food energy to be consumed.

I predict that the next major thrust of research will be in the application of nuclear power to California's agriculture, since nuclear power seems to be the cheapest—with due consideration for cleanliness—power source for the 1980's and thereafter. Nitrogen fertilizers from nuclear-powered electrical generators, and hydrogen gas for fuel look particularly promising because "off-peak" electrical power can be used to make hydrogen by electrolysis. Electrolytic hydrogen has, for some time, been combined directly with nitrogen to form ammonia in India and Egypt (though not in the United States at present).

In the 1870's we looked to India and Egypt for guidance in developing irrigation for our semiarid Western States. Perhaps in the 1970's we will be looking to them again for new directions in contending with the United States' impending fuel shortages.

—From an editorial by Perry R. Stout, professor of soil science and chemist, Agricultural Experiment Station, University of California, Davis, in *California Agriculture,* vol. 26, No. 12.

A LOOK AT USDA's BIOLOGICAL CONTROL OF INSECT PESTS: 1888 TO PRESENT

R. I. SAILER

RESEARCH on biological control of insect pests has been carried out by the U.S. Department of Agriculture since 1888. That was the year Albert Koebele was sent to Australia to obtain natural enemies of the cottonycushion scale, a pest that was causing heavy losses to California orange growers.

Koebele's trip was financed by $2,000 ostensibly appropriated for the purpose of paying the expenses of an entomologist to accompany the U.S. Commissioner to the Melbourne Exposition. Included in the material Koebele sent from Australia were 129 specimens of the vedalia beetle. These were placed on a scale-infested orange tree in what is now the city of Los Angeles. The beetles reproduced rapidly and, with some help from citrus grove owners and the Los Angeles County Board of Horticultural Commissioners, they soon spread throughout the county. Within one year shipments of oranges jumped from 700 to 2,000 cars. The vedalia beetle had saved the infant California citrus industry—and $500 of the original $2,000 remained unspent (*9*).

The spectacular success of this venture was followed by almost continuous work on the importation of beneficial insects for use against many crop and forest pests. Beginning in 1944 the method was extended to weeds.

Some Major Targets

THE first large-scale project was mounted in 1905 against the gypsy moth and continued to the outbreak of World War I. This effort was renewed during the period 1922 to 1933. Other major efforts have been undertaken against outbreaks of new pest invaders. The more important of these were the alfalfa weevil in Western United States (1911), European corn borer (1919), Japanese beetle (1920), oriental fruit moth (1930), Comstock mealybug (1939), citrus blackfly in Mexico (1943), Klamath weed (1944), oriental fruit fly (1947), Rhodesgrass scale (1949), pink bollworm (1952), spotted alfalfa aphid (1955), alfalfa weevil in Eastern United States (1957), alligatorweed (1960), and the cereal leaf beetle (1963).

In addition to importing natural enemies of the gypsy moth, the Department has introduced natural enemies of other forest insect pests. Among the more important of these pests are the balsam woolly aphid, European pine shoot moth, larch casebearer,

European spruce sawfly, elm leaf beetle, browntail moth, satin moth, and smaller European elm bark beetle.

Moreover, as a byproduct of the Department's work on major pests, many parasites and predators of other insect and weed pests of lesser importance have been obtained and successfully colonized in the United States. USDA entomologists have also actively helped with parasite introduction activities of California and Hawaii. Both States have maintained biological control programs since the time of Koebele.

Research on the Rise

WITHIN the Department, support for biological control through introduction of beneficial insects from foreign countries has reflected the general trends of applied entomology in the United States. Following the success of the vedalia beetle against the cottonycushion scale, entomologists hastened to apply the method as widely as possible. As new foreign pests appeared and became destructive, the number of entomologists employed by the Department increased. A high proportion of these were engaged in research on biological control.

This is indicated by a count of research publications, which shows that the ratio of biological control research to insecticide research in 1915 was 1 to 1. In 1925 a ratio of 0.3 to 1 showed a marked shift toward insecticide research. This trend continued up to World War II, when about six insecticide papers were published for each paper on biological control. In 1946 the ratio had reached 20:1. By 1955 the trend had reversed with a more favorable ratio of 7:1. In 1965 it was 4:1 and in 1970, 3:1. It should be noted that these figures do not include papers on autocidal control utilizing the sterile male or other techniques. They do include papers on plant resistance to insects.

As the figures indicate, the shift from biological control started prior to 1925. However, during the same period the number of entomologists employed by the Department increased rapidly as new problems arose, and need for increased production grew. As a result the number of entomologists employed in the field of biological control also increased up to the beginning of World War II. At that time there were about 40 entomologists in USDA who worked entirely in the field of biological control. This number declined rapidly during the 1940's and reached a low point in 1954 when only 5 man-years were actually devoted to biological control research on crop pests and 0.5 man-years on weeds.

New Problems Arise

AT about this time entomologists became aware of problems that suggested need for renewed interest in biological control. Insect pests were becoming resistant to DDT and other insecticides. There was increasing concern over residues and new pests were coming to the fore because their natural enemies had been destroyed by the broad-spectrum insecticides. The Entomology Research Division immediately began to seek alternative methods of pest control and to strengthen research on parasites, predators, and pathogens. By 1965 the number of man-years had increased to 52:6; however, as a result of general curtailment of Government expenditures, only 43 entomologists were employed for this work in 1972.

Work Abroad

DURING the early era, 1905 to 1919, the Department of Agriculture sent entomologists to Europe on temporary assignments, primarily for work on gypsy moth and alfalfa weevil. In 1919 the Department established a station at Auch, France, for research on parasites of the European corn borer. This station was relocated to Hyeres, France, in 1922 and in 1936 it was moved to a suburb of Paris. During this period the Department also had stations at Budapest, Hungary, for work on the gypsy moth and at Antibes, France, where research was conducted on the oriental fruit moth. All European work was consolidated at Hyeres in 1934.

USDA entomologists were also stationed in Japan more or less continuously from 1920 until the outbreak of World War II. Work in Japan resulted in introduction of parasites of the Japanese beetle, gypsy moth, satin moth, oriental moth, oriental fruit moth, and the European corn borer. With the outbreak of World War II, the entomologists in France were moved to Montevideo, Uruguay, where studies were conducted on the whitefringed beetle, vegetable weevil, and other pests, until 1947 when a laboratory was reestablished in France, again in a suburb of Paris.

The USDA was also involved in extensive exploration for parasites of the Mediterranean fruit fly

and other fruit flies. This work was done in cooperation with the Hawaiian Board of Commissioners of Agriculture and Forestry and involved extensive travel by USDA entomologists in Asia and Africa during the years 1948 to 1951. There was also a USDA station in India from 1952 until 1958. One entomologist was employed at the Indian station to find parasites of the pink bollworm but he also discovered parasites of the pea aphid and Rhodesgrass scale as well as two weevils that attacked the noxious weed, puncturevine, all of which have proved valuable in the United States.

The Department also engaged in foreign exploration for parasites of the citrus blackfly, first in cooperation with the Government of Cuba in 1930 and with Mexico during the years 1948–50. As a result the pest was quickly brought under highly effective control in both countries. This greatly reduced the threat posed by the citrus blackfly to citrus production in the United States.

After reaching a low ebb during the early 1950's there was no appreciable increase in overseas work until 1956 when increased interest developed in biological control of weeds. Laboratories for this work were set up at Tehran, Iran (1957) and Rome, Italy (1959), and in 1962 an entomologist was stationed in Buenos Aires, Argentina, to work on insects attacking aquatic weeds. The laboratories in Rome and Buenos Aires remain as centers for foreign research on weeds but they have also contributed to work on insect pests. Since 1960 there has been a substantial increase in the Department's overseas activities in the field of biological control. The Paris laboratory has expanded research on the alfalfa weevil, cereal leaf beetle, and most recently the gypsy moth. In addition, through the special foreign currency research programs (SPC) of the International Programs Division of USDA's Agricultural Research Service (ARS), 26 research projects are now being supported in 7 countries. In 1971 the dollar value of the foreign currencies utilized to support these biological control research projects amounted to $1,744,000.

Fears are often expressed in some quarters that insects brought in from foreign countries to control other insects or to control weeds will themselves become pests. The record here speaks for itself. Of the 620 beneficial species brought into the United States, not one is now known to have any economic importance as a pest. The intentional introduction of the gypsy moth and its subsequent escape has been cited as a cautionary example. It should be remembered that the gypsy moth was brought into the United States more than a century ago by a person with no formal training in entomology and who knew little of the moth's biology and characteristics. Such an intentional introduction has not been possible since enactment of the Federal Quarantine Act of 1912.

Precautionary Measures

THE purpose of the overseas laboratories of ARS and much of the research conducted by scientists supported by SFC grants is to determine whether insects believed to be useful as parasites or predators of pests or as enemies of weeds can be safely imported. Up to 4 years have been spent in research needed to demonstrate that a weed-feeding insect will not attack any useful plant. Prior to each introduction of weed-feeding species, clearance for its importation must be obtained from a committee of experts representing different fields of agriculture, forestry, and wildlife. Concurrence must also be obtained from a comparable Canadian committee under an agreement whereby they obtain similar concurrence from the U.S. committee for their introductions. Finally, all imported beneficial insects are received at the ARS laboratories at Moorestown, N.J., or Albany, Calif., where they are placed in quarantine. The insects that are given a clean bill of health are removed from the specially designed quarantine facilities only after it is determined that no undesirable or unknown insects or other organisms are included. Where it has not been possible to complete all host specificity tests at a foreign station, weed-feeding insects are kept in quarantine until final tests are completed.

The SFC research program has also made available much information about the biology and control of many insect pests not known to occur in the United States. The information not only makes it possible to improve quarantine measures needed to prevent their entry but increases our ability to deal effectively with any that somehow enter the United States.

As indicated earlier, the Department has been engaged in biological control research for well over 80 years. It is fair to ask what benefits have accrued

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to the American farmers, orchardists, and foresters. Because of the span of time involved and problems of recordkeeping that arise from organizational changes and shifts of responsibility, exact statistics are not available. However, at least 420 beneficial species have been imported and colonized in varying numbers. Another 200 species have been imported and studied to some extent but not released. No less than 128 of the colonized species (inclusive of University of California introductions) are known to be established and effecting some degree of control over the pests that serve as their hosts. More than 60 insect pests and 10 weeds have been targets of USDA biological control programs. Of course there have been many failures. These must be attributed to a variety of reasons, many having little to do with the characteristics of the insects. Some of the introductions have been highly successful, in fact, so successful that their hosts are no longer considered to have significant importance as pests.

NOTABLE ACCOMPLISHMENTS

FOLLOWING are some of the accomplishments of USDA research on biological control of insect pests:

Alfalfa Weevil, *Hypera postica* (Gyllenhal)

THIS pest first appeared in Utah in 1904, and natural enemies were imported from Italy during the period 1911–13 (*5*). Additional importations were made in 1925–28 (*6*). Although several parasites were introduced and colonized, only one, *Bathyplectes curculionis* (Thomson), proved to have value as a control agent. It quickly dispersed throughout the Western States and could be found wherever the weevil occurred. Although it greatly reduced the weevil populations, in only a few places was it sufficiently effective to eliminate need for other controls.

The pest next appeared in Maryland in 1951 and by 1971 had occupied most of the eastern half of the United States. In all infested areas it was necessary to use insecticide in order to prevent total loss of the first crop. Initial attempts to introduce *Bathyplectes curculionis* from Idaho to Maryland failed, probably because of the almost universal use of insecticides. In 1957, *B. curculionis* was again imported, this time from Riverside, Calif., and released in New Jersey, where the species was easily established. The success here was due in great part to use of soil land where no insecticide was used. At the same time, alfalfa weevil parasites were being collected in France by the ARS Laboratory in Paris. During the period 1957–63 three additional European species were established in New Jersey: *Tetrastichus incertus* (Ratzeburg), *Microctonus aethiops* (Nees) and *Bathyplectes anurus* (Thomson).

As a result of dispersal from the Moorestown "beachhead" and subcolonization by entomologists, *Bathyplectes curculionis* spread rapidly and is now coexistensive with the weevil throughout most of the United States. *Tetrastichus incertus* is found over much of the Northeast while *Microctonus aethiops* has moved more slowly and occurs in an area extending about 200 miles in all directions from Moorestown (*4*). *Bathyplectes anurus*, a species likely to be most effective in Southern United States, has dispersed even more slowly but since 1970 appears to have gained momentum.

Beginning in 1966 a reduction in weevil populations was noticed in New Jersey. At first attributed

to weather, the trend continued. In 1968, farmers in New Jersey began to withhold treatment for alfalfa weevil and in 1969 less than 8 percent of the alfalfa growers of that State used insecticides against the weevil as opposed to 94 percent in 1967. The beneficial effect had spread in 1970 throughout an area from western Massachusetts through southeastern New York, eastern Pennsylvania south to Maryland. This area nearly coincides with the distribution of *Microctonus aethiops* which is believed to be a key parasite species responsible for reducing the weevil to below the economic threshhold.

As a result of work by ARS entomologists at Moorestown and their State cooperators, *Bathyplectes anurus* has been established at Blacksburg, Va., Harrison county, Ind., Lexington, Ky., and Columbia, Mo., while *Microctonus aethiops* is now firmly established in Michigan. A large-scale effort was made in 1971 to further disperse *Microctonus aethiops* and other parasite species.

On the basis of the past 3 years' experience, it appears certain that the parasite populations are expanding at an accelerating rate aided by discontinuance of insecticide treatments in the peripheral area of effective parasite control. We now have reason to predict with some confidence that the alfalfa weevil problem will be greatly reduced in severity throughout Eastern United States within 5 years.

Recently, calculations were made of the cost of the USDA research program on control of the Eastern outbreak of the alfalfa weevil starting with inception of work at Moorestown in 1957. All costs attributable to work on the weevil in Europe and at Moorestown amounted to $600,000. Savings to farmers during the year 1970 in the area where the weevil has been reduced to noneconomic levels amounted to more than $3,000,000. This took into consideration only the per acre cost of treatments *not* applied. Additional values in increased acreage of alfalfa planted because farmers no longer had to contend with the weevil and reduction in environmental contamination due to pesticides were not computed.

Browntail moth, *Nygmia phaeorrhoea* (Donovan)

AT the beginning of this century the browntail moth was a serious pest of orchards as well as shade and forest trees over a considerable area of New England. Large-scale importations of natural enemies from Europe were made from 1905–11, concurrently with work on the gypsy moth (*10*). About 20 species of parasites and predators were received, and several were successfully colonized. Two became effective enemy species. These are the parasitic wasp *Apanteles lacteicolor* Vier. and the tachinid fly *Townsendiellomyia nidicola* (Tns.). In addition this moth is attacked by the parasitic wasp *Meterorus versicolor* (Wesm.) imported for control of the satin moth and by the tachinid fly *Compsilura concinnata* (Meig.), originally colonized against the gypsy moth. It is also attacked by the predator *Calosoma sycophanta* (L.) originally introduced against the gypsy moth.

The browntail is no longer distributed over as large an area as it occupied in 1905 and it is seldom sufficiently numerous to be regarded as a pest at any locality.

Cereal leaf beetle, *Oulema melanopus* (L.)

THE cereal leaf beetle was first found in the United States in Michigan in 1962. In 1963, the ARS Laboratory in Paris initiated search for its natural enemies in Europe. Four parasite species were found and the first were shipped to the United States in 1964. USDA also established a facility at Niles, Mich., for propagation and dispersal of the European parasites. Through its extramural research program ARS has supported biological control research at both Purdue University and Michigan State University.

As a result of release of stock reared at the Niles facility, the egg parasite *Anaphes flavipes* (Foerster) was established in Michigan in 1967. It was recovered in 1968 (*3*) and by 1970 was found over an 8,000-square mile area of southern Michigan. Two larval parasites, *Tetrastichus julis* (Walker) and *Diaparsis carinifer* (Thomson) released by the USDA entomologists at Niles and by those of Michigan State University have become established at several locations in Michigan. At the university's Gull Lake Experiment Farm, as a result of planned management, the population of *Tetrastichus julis* built up to a point that permitted large numbers to be collected for dispersal throughout Michigan,

Indiana, and Ohio during 1971. In 1972 the species was recovered from 17 counties in Michigan.

In the meantime, additional stock of the parasites has been collected each year by ARS Paris laboratory personnel and by SFC-supported entomologists in Yugoslavia and Poland. This stock is being released to hasten general colonization of the parasites and to insure maximum genetic vigor of the new parasite populations. Now in its 10th year, this project is reaching the "payoff" point. The population of the cereal leaf beetle is declining in the vicinity of the Gull Lake Experimental Farm, and in another 3 years there is a good prospect that the effect will be general in southern Michigan.

Citrus blackfly, *Aleurocanthus woglumi* (Ashby)

THE citrus blackfly is potentially one of the most destructive pests of citrus. First discovered in Mexico in 1935, it spread rapidly throughout that country and was an obvious threat to the citrus industry of the United States. The Department through its then Bureau of Entomology and Plant Quarantine responded to the Mexican Government's request for assistance and in 1938 introduced the first parasites for control of the pest. These belonged to the species *Eretmocerus serius* Silvestri, a parasitic wasp that the Bureau had previously introduced into Cuba from Malaya. In Cuba this parasite completely controlled the citrus blackfly in 2 years, but it proved ineffective in Mexico. The Department then sent an entomologist to India and Pakistan where additional citrus blackfly parasites were known to occur. During 1948–49, shipments from this source resulted in establishment in Mexico of 4 parasite species, *Amitus hesperidum* Silv., *Prospaltella clypealis* Silv., *P. opulenta* Silv., and *P. smithi* Silv.

The initial colonization of these parasites was directed by a second USDA entomologist. Later the entomologist who shipped the parasites from the Orient took charge of the work in Mexico and guided an elaborate cooperative redistribution program under the "Comite National de Combate y Control de la Mosca Prieta des los Citricos." An estimated 400,000,000 parasites were distributed throughout Mexico during the period 1951–57. By the end of this period biological control was virtually complete throughout the country (18). To protect citrus in California, Arizona, and Texas, the Department has, in cooperation with the Mexican Government, maintained a barrier zone on the Mexican side of the border where all infestations are eliminated by chemical treatment. It was possible to maintain this zone and to prevent entry of the pest until 1971, in great part because of the highly effective control provided by the parasite in the rest of Mexico. The pest is now established in south Texas where biological control is complicated by extensive use of insecticides against cotton and other crop pests in fields adjacent to or near the citrus groves.

European corn borer, *Ostrinia nubilalis* (Hübner)

THIS pest attacks not only corn but a variety of other field crops and vegetables. First discovered in Massachusetts in 1917, it was immediately recognized to be a major threat to one of our most important grain crops, and biological control investigations were started by the USDA in France in 1919. The search for natural enemies in Europe was concentrated mainly in France and Italy. Importations from that region during the years 1920–38 totaled approximately 2,687,000 adult parasites. Collections in Japan, Korea, and Manchuria made during 1929 through 1936 added another 307,000. These were supplemented later in a colonization program by 3,360,000 of five species produced by domestic rearing and by field collections of 146,000. Additional field collections of several of the established species for extension of colonization were made annually from 1939 to 1955.

Of the 24 species of parasites that were imported and colonized, six became established—*Chelonus annulipes* Wesmael, *Horogenes punctorius* (Roman), *Lydella thompsoni* Herting, *Macrocentrus grandii* Goidanich, *Phaeogenes nigridens* Wesmael and *Sympiesis viridula* (Thomson). Only *Lydella thomsoni* and *Macrocentrus grandii* became sufficiently abundant and widely distributed to be considered of appreciable value in field control. *Lydella thompsoni* was by far the most effective of the introduced species (*6*).

During the years 1948–50, surveys in 25 States showed that *L. thompsoni* was parasitizing 10 percent to over 50 percent of the hibernating borers. The number destroyed by the midsummer genera-

tion was never established but would have been a serious tax on the first borer generation. Coincident with the general high mortality caused by this tachinid fly, the corn borer populations subsided to low and generally noneconomic levels and remained so during most of the next decade, only to resurge during recent years to levels that are once more causing concern.

Interestingly enough, sometime between 1955 and 1965 *Lydella thompsoni* appears to have disappeared from the Corn Belt. Reasons for this are not known but are suspected to relate to the development of hybrid varieties of corn highly resistant to borer, and to changes in cultural practices. It is possible that these factors combined to reduce the borer population to a level that would no longer sustain the parasite population. Now only *Macroncentrus grandii* and *Sympiesis viridula* can be found in any numbers. Whether the resurgence of the corn borer is related to the absence of *L. thompsoni* is not known.

It is thus difficult to evaluate the benefits of the most ambitious biological control program ever carried out by the Department. At best it may be said that *L. thompsoni* bought the time needed to develop and place in production the borer-resistant hybrid varieties of corn.

Florida red scale, *Chrysomphalus aonidum* (L.)

CONTROL of this pest of citrus in Florida as a result of introduction of the scale parasite, *Aphytis holoxanthus* DeBach, is highly illustrative of the importance of cooperation and coordination between Federal, State, and foreign entomologists. In 1955 an entomologist in Israel wrote entomologists of the California State Citrus Research Station and asked for names of known parasites of Florida red scale, a serious pest in Israel at that time. He was advised that a promising species was known to occur in Hong Kong. He obtained shipments in 1956 that contained an *Aphytis* that was readily colonized and by 1959 caused complete control of Florida red scale in Israel (*7*).

In the meantime, the California entomologists arranged with USDA entomologists to obtain stock of the *Aphytis*. This was necessary since the parasite could only be moved in its host on citrus that could not be imported into California because of quarantine regulations. The Department's entomologists at the ARS Introduced Beneficial Insects Quarantine Receiving Station at Moorestown, N.J., received the parasites from Israel, transferred them to California fruit and thus forwarded clean stock to California. There the species was studied and described as *Aphytis holoxanthus*. In 1960, a Department entomologist requested stock from California for release in Florida. This was received, colonized and by 1963, the species was established throughout the State (*14*). The incidence and intensity of Florida red scale infestations dropped abruptly and remain at a fraction of the previous level. This high degree of control is also remarkable in that it was accomplished despite chemical control measures regularly applied against other pests. At about the same time purple scale *Lepidosaphes beckii* (Newm.) in Florida was controlled by *Aphytis lepidosaphes* Compere, a species previously imported into California from the Orient by State entomologists. Presence of this parasite in Florida was discovered when the Department entomologist and his State counterpart were preparing to colonize stock of it received from California (*14*).

Gypsy moth, *Porthetria dispar* (L.)

THIS pest of forest, shade, fruit, and ornamental trees was brought to the United States in 1868 by a Professor Leopold Trouvelot who was associated with the Astronomical Observatory of Harvard University. As a hobby, Professor Trouvelot studied wild silkworms. He hoped through cross breeding different species to produce a hardier insect than the silkworm of commerce and one that would feed on trees other than mulberry. It seems likely that he had little knowledge of the gypsy moth beyond the fact that the color and appearance of the adults were similar to the silkworm. Had he known that the gypsy moth spins no cocoon it is unlikely that he would have bothered to obtain egg clusters from France.

When the eggs hatched in the spring of 1869, he placed the larvae on a shrub in the yard of his home in Medford, Mass., taking only the precaution of covering them with a cheesecloth net. When the net was torn during a storm he attempted to retrieve all

the caterpillars and published an announcement of their escape. The matter was soon forgotten. Twenty years passed before the gypsy moth again came to public attention and another 5 years before work was started on introduction of natural enemies.

Large-scale importation of natural enemies from Europe and to a lesser extent from Japan were carried out from 1905–14. A second effort was made in 1923–33, and since 1960, parasites have been imported intermittently from Spain and India. In 1972 the ARS Laboratory in France initiated new research in Europe designed to find more effective parasites for use in the United States. As a result of this foreign work, 50 species of parasites have been imported and colonized (*10*). However, only 10 species of parasites and 2 species of predators have become established.

Among the important parasites, two attack the egg stage. *Anastatus disparis* Ruschka from Europe is established in New England while *Ooencyrtus kuwanai* (Howard) from Japan occupies the more southern part of the gypsy moth's present range. Among the larval parasites, the flies *Compsilura concinnata* (Meigen) and *Blepharipa scutellata* (R–D), *Parasetigena agilis* (R–D), and the wasp *Apanteles melanoscelus* (Ratz.) are the most effective. *Compsilura concinnata* often destroys 40 percent or more of the moth larvae and is widely distributed even beyond the range of the gypsy moth. *Blepharipa scutellata* is frequently obtained from 70 percent of all populations sampled. *Apanteles melanoscelus* ranks third in importance and though variable in extent of its attack, each of its two broods often parasitize 20 to 30 percent of the larvae (*10*). In New Jersey during 1972, *Parasetigena agilis* was found to be the dominant gypsy moth parasite.

After having been thought to have failed to establish, the pupal parasite *Brachymeria intermedia* (Nees) is now known to be numerous from southeastern Maine to Connecticut and is being reared and released in large numbers in New Jersey and Pennsylvania at the present time. A native parasite, *Itoplectis conquisitor* (Say), is also known to destroy large numbers of pupae.

Of the two predators to become established, the carabid *Calosoma sycophanta* (L.) is one of the most important natural enemies of the gypsy moth. The large, metallic, blue-green ground beetle originally from Europe climbs trees to attack both larvae and pupae. At various times and places it becomes very abundant and destroys an appreciable proportion of the gypsy moth population.

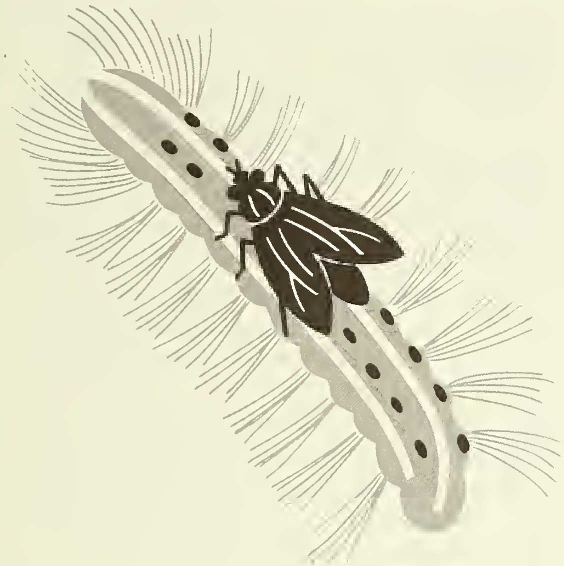
Another important natural agent in control is a wilt or polyhedral virus disease *Borrelina reprimens* (Holmes). This is common in Europe and first appeared in the United States in 1907. It was probably imported unintentionally with the large numbers of caterpillars brought to the United States during the parasite-introduction program. It assumes epidemic proportions only in heavy infestations, which are often almost completely destroyed.

The benefits of the introduction program against the gypsy moth have never been systematically evaluated. It is apparent, however, that the combined effect of the parasites and predators, together with the wilt disease, has provided a substantial degree of control. Instead of occurring as epidemic populations terminated only by death of susceptible forest trees as was characteristic of the pest prior to 1915, the outbreaks are now reduced, at least in the New England area, to a level comparable in range and severity to those occurring in Europe.

As might be expected, the severity of outbreaks in the United States at present is greatest in the areas most recently invaded. It is perhaps no coincidence that these are the areas where the most strenuous efforts have been made to control or eradicate the pest. The insecticides used could not have failed to eradicate the introduced parasites from the treated areas. As the moth reentered the treated areas and spread to previously uninfested areas, it again exhibited the worst characteristics of an invading foreign species.

Japanese beetle, *Popillia japonica* (Newman)

IN 1916 some strange beetles were found in a nursery in New Jersey. These were later identified as *Popillia japonica* known to occur on the main islands of Japan. Importations of parasites were started in 1920 and continued until 1933. In the material shipped to the United States, there were 15 enemy species, of which four were fly parasites of the adult beetle, two were fly parasites of the grubs and eight were wasp parasites of the grub; one species was a ground beetle predator. Five became established in the infested areas of northeastern



United States, but only two of the wasp species, *Tiphia popilliavora* Rohwer and *T. vernalis* Rohwer adapted themselves to local conditions and became generally distributed. Both species were heavily dependent on adult food sources and *T. vernalis* became numerous only in the neighborhood of abundant aphid honeydew while *T. popilliavora* preferred the nectar of wild carrot.

The importance of these parasites was further diminished when the bacterial disease caused by *Bacillus popilliae* Dutky and related species was found. These are believed to be native pathogens of American species of white grubs. In areas where the milkyspore disease is active, the beetle grub population appears to become too low to sustain the parasites.

Following this discovery, a process was devised for producing the spores of the *Bacillus* in the blood of the grubs and incorporating the spores into a dust for storage and distribution in the field. The spores were colonized extensively during 1939–53 in 14 States and the District of Columbia. It was estimated at the conclusion of the colonization that over 244,000 pounds of spore dust had been applied at over 160,000 sites. Undoubtedly, spores were and are being further distributed by birds that feed on diseased grubs. The result has been a high degree of control in most areas infested by the beetle more than 5 years (*11*).

Larch casebearer, *Coleophora laricella* (Hübner)

THE larch casebearer is of European origin and now occurs throughout the range of its host in Northeastern and Northwestern United States. Importations of large numbers of its natural enemies from central Europe were undertaken in 1932–37. Of the 11 species shipped and released, two are known to be established, *Chrysocharis laricinellae* (Ratz.) and *Agahis pumila* (Ratz.). Almost total control was quickly obtained in the Northeastern States and because *pumila* was the more abundant, control was attributed to this species alone (*10*). It has since been shown that presence of *C. laricinellae* is necessary in order for *A. pumila* to develop its high populations (*16*). This appears to be confirmed by results of introducing only *A. pumila* into Montana and Idaho where a large-scale outbreak of the casebearer has more recently occurred. Although established there since 1965, and despite much effort expended to distribute the species, *A. pumila* has failed to provide effective control. Efforts will now be made to introduce additional species.

Oriental fruit moth, *Grapholitha molesta* (Busck)

THE oriental fruit moth became a most destructive pest of peaches soon after its discovery in the United States in 1916. Importation of natural enemies was undertaken in 1930 and continued until 1939. Most of the foreign parasite collections were made in Japan and Korea though some consignments were received from France, Italy, and Australia. Total importations yielded 230,500 parasites and included more than 20 species. With one or two exceptions all species were colonized in infested areas of the Eastern States, some in very large numbers at many locations. Several species, notably *Horogenes molestae* (Uchida), reproduced well in the field during the season of release and showed considerable promise. Unfortunately the colonies declined sharply after the first season and eventually disappeared. Presumably this was due to absence in the United States of suitable alternate hosts. Only one species *Agathis diversa* (Muesebeck) is known to have persisted but it has been of little value for control (*1*).

However, as a result of the domestic work on

biological control, a native species, *Macrocentrus ancylivorus* Rohwer, previously reared only from the strawberry leafroller was found to attack the oriental fruit moth. It quickly adapted to the new pest and attained a high degree of parasitization. *Macrocentrus ancylivorus* proved to be easily reared in the laboratory on potato tuberworm and when the oriental fruit moth invaded California, it became the first parasite mass reared and released in an attempt to eradicate a pest. During the years 1944 through 1946, more than 15,000,000 were reared annually and colonies were placed in each infested orchard. Although the attempted eradication was unsuccessful, many incipient infestations disappeared. Despite the number released the parasite failed to become established in California, again because of the absence of an alternate host. However, for reasons not understood, the pest has never attained injurious levels comparable to those common in the Eastern States.

Oriental moth, *Cnidocampa flavescens* (Walker)

THIS pest of several shade and ornamental trees was first found in Boston in 1906, and by 1917 had spread over a considerable surrounding area. Initial attempts (1917–18) to introduce parasites from China failed and the moth continued to spread. A second attempt in 1929–30 resulted in importation and successful colonization of a tachinid fly *Chaetexorista javana* B. & B. obtained in Japan. The parasite increased and spread very rapidly and by 1933 surveys showed 63.5 percent of the host larvae to be attacked. Since that time, the oriental moth has ceased to have importance as an economic pest. It has spread little beyond its 1933 range and poses no threat to the rest of the United States (*10*).

Rhodesgrass scale, *Antonina graminis* (Maskell)

IN 1940 ranchers in eastern Texas found that their formerly lush Rhodesgrass pastures were no longer productive. The cause was soon determined to be a scale insect, *Antonina graminis*. One parasite, *Anagyrus antonina* Timberlake, was known to occur in Hawaii. This was imported in 1949 and reared and released in large numbers by the Texas Agricultural Experiment Station. Although it became established it failed to control the pest. Several additional parasites were imported from the ARS Laboratory in France. These were obtained from related scale insects but could not be colonized on Rhodesgrass scale.

In 1956 an ARS entomologist in India who was searching for pink bollworm parasites found a parasite attacking Rhodesgrass scale. This parasite was described and is now known as *Neodusmetia sangwani* (Subba Rao). In 1959 ARS obtained stock from India and made it available to the Texas Experiment Station where work was supported by a USDA cooperative agreement. This parasite was quickly established and found to effectively control the scale. Techniques were devised to distribute the parasites by air at a cost of 34 cents per acre. In 1965 and 1966, 900,000 acres of Texas pasture land were colonized. In areas where the parasites are now established, Rhodesgrass can again be grown and forage production has increased to normal levels (*17*).

Rhodesgrass scale was also a serious problem in Florida during the 1940 decade. The Hawaiian parasite, *Anagyrus antoninae,* was released there in 1949 and immediately established. It was soon credited with control of the scale. However, in 1957, two small shipments totaling 24 *Neodusmetia sangwani* were released at Belle Grade. Additional small releases were made in 1959. In 1970 careful search failed to reveal the presence of *Anagyrus antoninae;* all parasites recovered were *N. sangwani*. It therefore appears that this parasite is making an important contribution to forage production in Florida as well as in Texas.

Satin moth, *Stilpnotia salicis* (L.)

THE satin moth was first discovered in this country at Medford, Mass., in 1920 and 2 years later it was found at Bellingham, Wash. When this shade and forest tree pest was first discovered in New England, it was already being attacked by several species of parasites originally introduced against the gypsy moth. Between 1927 and 1934, several more species were imported from central Europe and all the promising species were colonized in the Pacific Northwest. Those known to be established in the Northeast are the parasitic wasps, *Apanteles solitarius* (Ratz.) and *Eupteromalus hemipterus* (Walker) (= *nidulans* (Thomson)) and the tachnid flies *Compsilura concinnata* (Meigen), and *Exorista larvarum* (L.). The first three are estab-

lished in the West together with a third parasitic wasp *Meteorus versicolor* (Wesm.). Attempts to colonize the latter in the East failed.

In both areas the parasites are holding the pest in very low levels. Occasional local outbreaks soon subside and the pest is behaving as a native species rather than as an aggressive foreign invader (*10*).

Smaller European elm bark beetle, *Scolytus multistriatus* (Marsham)

THIS beetle is a vector of the devastating Dutch elm disease. No efforts were made to introduce enemies of this insect until 1964 when the first stock of the parasite *Dendrosoter protuberans* (Nees) was shipped from the ARS Paris laboratory to the Forest Service Laboratory at Delaware, Ohio. There the species was propagated and reinforced by additional stock obtained by the Paris laboratory. The parasite has been released in Ohio, Missouri, Illinois, the District of Columbia, and New Jersey (*12*). Stock was also supplied Michigan State University where the species was propagated and released at many places in Michigan. From Michigan large shipments were made to New York.

At present the parasite is known to be established only in Detroit, Mich. (*13*), but because of difficulties in recovering it in the field, probabilities are good that it is established at other localities. In France, *Dendrosoter protuberans* regularly destroys 30 to 70 percent of the beetles developing in infested trees. If the species can be successfully established throughout the United States, it should perform equally well against beetles developing in wild elm growing along stream courses, fence rows, and in wood lots. Without the overwhelming beetle populations originating from these sources, there is hope that a new generation of elm trees will not be destroyed by a recurring epidemic of Dutch elm disease.

Spotted alfalfa aphid, *Therioaphis maculata* (Buckton)

IN 1954 the spotted alfalfa aphid suddenly appeared in damaging numbers in California. It quickly spread across the Southwest and eventually occupied most of the southern half of the United States. It was soon recognized as an accidental immigrant from the Old World, where it was known to be commonly attacked by parasitic wasps. A cooperative program for biological control of the new pest was undertaken in 1955 by ARS and the Department of Biological Control of the University of California. This program progressed rapidly on two fronts: (1) importation of natural enemies from the Middle East and (2) development of alfalfa varieties resistant to spotted alfalfa aphid attack.

The search for natural enemies yielded three species of parasites: *Praon palitans* (Muesebeck), *Trioxys complanatus* Quilis, and *Aphelinus asychis* (Walker). These were successfully mass produced in insectaries at Moorestown, N.J., and at Albany and Riverside, Calif. Parasites were released in large numbers at many localities in California, Arizona, Texas, Oklahoma, and other States. By the end of 1957, in California alone, they were established in areas involving about 1,000,000 acres of irrigated alfalfa and were playing an increasing role in control of the aphid (*19*).

At the same time excellent progress was being made in developing resistant strains of alfalfa. These strains were soon grown over much of the alfafa acreage in the Southwest. By 1958, the spotted alfalfa aphid outbreaks had subsided and for more than a decade there has been no repetition of the disastrous outbreaks of the period 1954–57.

The relative importance of the parasites and the plant resistance in bringing about control has been disputed. It seems likely that both contributed to

this outstanding example of biological control of an important pest.

Concluding Remarks

In a recent publication Paul DeBach (*8*) has reviewed the results of moving natural enemies from one part of the world to another for control of pests. He reports that during the period 1888 to 1969, 223 species of insect pests were targets of such action. Some degree of control was achieved against 120, or more than half of the pest species involved. For 42 of the 120 species complete control resulted, and for 38, economic injury was substantially reduced. In his discussion of cost benefits, DeBach cites figures showing that savings resulting from reduced treatment costs and reduction in crop losses have returned $30 for each dollar invested in importation and colonization of natural enemies. By comparison each dollar spent on insecticides returns $5 in benefits (*15*). However, to place these figures in proper perspective it should be noted that the total cost of all parasite introduction research during the past 80 years would be but a small part of the $420,000,000 spent annually on insecticides (*2*).

That great benefits have resulted from movement of parasites and predators as well as insect enemies of weeds from one country to another is incontrovertible. And, in terms of benefits, no country has profited more than the United States. As indicated by the accomplishments discussed earlier, the USDA has made notable contributions to control of pests through importation and colonization of natural enemies. However, as will be noted from names of authors included in the list of references cited in this paper, much of this work has involved close cooperation between USDA and State experiment station scientists. Also, quite apart from cooperative endeavors, scientists of the University of California, as well as scientists employed by the Sugar Planters Association and the Department of Agriculture of Hawaii, have for many years maintained highly successful introduction programs.

Finally, in this time of concern about the impact of man's activities on the environment, it may not be inappropriate to comment on another aspect of beneficial insect introduction research. When Europeans first settled in North America they found the flora and fauna organized into natural ecosystems that were little affected by man. Since that time the ecology of the continent has been changed. In developing the agro-ecosystems that now occupy most of the United States, European immigrants adopted and greatly expanded the culture of such native crop plants as corn, potatoes, cotton, and tobacco. They brought with them wheat and other small grains, forage crops, vegetables, and fruit trees.

Inadvertently, they also brought weeds and insect pests that thrived because few were accompanied by the natural enemies present in the agro-ecosystems of Europe. As commerce reached out to other parts of the world new pests continued to arrive, again without the enemy species that had evolved with them in their native ecosystems. The resulting population explosions of pest species have been a phenomenon all too familiar to American agriculturists. Such pests as the Hessian fly, codling moth, San Jose scale, gyspy moth, European corn borer, and oriental fruit moth are but a few of the insect pest invaders. It was largely thanks to these invaders from overseas and the boll weevil from Mexico that economic entomology first developed in the United States and achieved world eminence under the leadership of the USDA.

How does this relate to ecological aspects of agriculture and public concern about the environment? In a few words—the importation and colonization of beneficial insects tend to enrich agro-ecosystems that otherwise tend to become progressively impoverished. There is the trend toward larger farm units and increasing crop acreages grown under conditions of monoculture. Genetic variability of crops diminishes as plant breeders develop high yield cultivars that are then grown over entire production areas. Entomologists and chemists contribute through development of insecticides that control pests and at the same time eliminate insect parasites and predators.

It is fortunate indeed that all changes resulting from research designed to improve agricultural productivity do not promote reduced agro-ecosystem complexity. The efforts of USDA plant explorers have added new crops, new ornamental plants, new crop varieties and new germ plasm for old varieties, while USDA parasite explorers and biological control scientists have imported many beneficial parasites and predators of insect pests as well as insects that attack noxious weeds. Although done for economic reasons, this research has added complexity

and resilience to American agro-ecosystems, and a great deal more could and should be done to increase the diversity and stability of these systems.

Popular and even scientific literature present the picture of a world "combed" for beneficial insects. How far this view departs from fact is evident from a recent tabulation of alien insects now resident in the United States (*20*). Names of 1,100 species are included. Of this total only 128 are purposely introduced beneficial species. Of those that remain, 615 are species known to have some adverse economic importance. Included in this latter figure are 217 pests of major importance. These, because of their foreign origin, are particularly favorable targets for parasite introduction programs, and since each in its native ecosystem normally supports three or more kinds of parasites or predaceous insects, it is evident that the 128 purposely introduced beneficial species are but a small part of those that could usefully be added to the American agro-ecosystems.

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INTEGRATED PEST MANAGEMENT

PRIOR to the late 19th century, plowing, planting, and watering schedules were the main methods used to control pest levels. Toward the turn of the century and up until the mid-1940's, organic plant derivatives and minerals, such as sulfur and arsenic-containing compounds, were used for pest control. Over the last 3 decades, they have been largely replaced by synthetic chemical pesticides.

Despite the recent emphasis on chemical pesticides, a number of promising alternative pest control techniques have been used to varying degrees. These involve environmental manipulations or cultural methods (such as changes in planting, plowing, fertilizing, and watering practices), genetic changes (in both crop resistance and pest susceptibility), biological controls (the release of pest predators and parasites), pest-specific diseases and hormones, and pest sterilization. Use of these techniques along with improved methods of applying pesticides may result in reducing the overall need for chemical pesticides.

Integrated pest management is an approach which maximizes natural controls of pest populations. An analysis of potential pest problems must be made. Based upon knowledge of each pest in its environment and its natural enemies, farming practices are modified (such as changes in planting and harvesting schedules) to affect the potential pests adversely and to aid natural enemies of the pests. If available, seed which has been bred to resist the pests should be planted.

Once these preventive measures are taken, the fields are monitored to determine the levels of pests, their natural enemies, and important environmental factors. Only when the threshold level at which significant crop damage from the pest is likely to be exceeded should suppressive measures be taken. If these measures are required, then the most suitable technique or combination of techniques, such as biological controls, use of pest-specific diseases, and even selective use of pesticides, must be chosen to control a pest while causing minimum disruption of its natural enemies. This approach differs markedly from the traditional application of pesticides on a fixed schedule.

A growing pest management industry centered primarily in the Southwest and West has shown that integrated pest management can be both effective and economical. Although evidence of its overall economic advantage is still incomplete, its economic benefit for crops which use relatively large amounts of pesticides is clear. For crops using less pesticides, the economic advantage is likely to be smaller except where yields are increased by improved pest control. In general, use of the integrated pest management approach should lead to greatly reduced environmental contamination from pesticide use and to many fewer problems with pest resistance and secondary outbreaks while maintaining or improving our current ability to prevent pest damage.

In spite of its many benefits, integrated pest management is still not in widespread use—probably because of a variety of attitudinal factors as well as economic and personnel constraints. Some of the reasons include the farmers' lack of incentive to change pest control practices, the complexity of these new management techniques, fear of crop loss, inadequate information on economic threshold levels, an inadequate supply of trained professionals, and a limited number of fully developed nonchemical or selective chemical control methods.

Development of these alternatives depends upon research and upon knowledge of the pest, including its behavior, metabolism, and the important ecological factors which affect it.

Integrated pest management holds the promise of better pest control with minimum adverse environmental effects at lower costs to the farmer. But its widespread adoption depends on surmounting a host of technical and attitudinal barriers. The Federal Government can help, but the long-term success of integrated pest management depends upon the States, the universities, the private integrated pest management industry, and ultimately the farmer.

This is from the summary, issued in November 1972, of "Integrated Pest Management" prepared by the Council on Environmental Quality, Russell E. Train, Chairman.

HUMANIZING THE EARTH

RENÉ J. DUBOS

HOW grey and drab, unappealing and unsignificant our planet would be without the radiance of life. The surface of the Earth would resemble that of the Moon if it were not covered with living organisms. Its colorful and diversified appearance is largely the creation of microbes, plants, and animals which endlessly transform its inanimate rocks and gases into an immense variety of organic substances. Man augments still further this diversification by altering the physical characteristics of the land, changing the distribution of living things, and adding human order and fantasy to the ecological determinism of nature.

Many of man's interventions into nature have, of course, been catastrophic. History is replete with ecological disasters caused by agricultural and industrial mismanagement. The countries which were most flourishing in antiquity are now among the poorest in the world. Some of their most famous cities have been abandoned; lands which were once fertile are now barren deserts.

Disease, warfare, and civil strife have certainly

played important roles in the collapse of ancient civilizations; but the primary cause was probably the damage caused to the quality of the soil and water supplies by poor ecological practices. Similarly today, the environment is being spoiled in many parts of the world by agricultural misuse or overuse, by industrial poisoning, and of course by wars.

The primary purpose of the recent U.N. Conference on the Human Environment, held in Stockholm in June 1972, was to formulate global approaches for the correction and prevention of the environmental defects resulting from man's mismanagement of the Earth. I shall not discuss the technical aspects of these problems but rather shall try to look beyond them and present facts suggesting that man can actually improve on nature. In my opinion, the human use of natural resources and of technology is compatible with ecological health, and can indeed bring out potentialities of the earth which remain unexpressed in the state of wilderness.

The disastrous ecological consequences of many past and present human activities point to the need for greater knowledge and respect of natural laws. This view is succinctly expressed by Dr. Barry Commoner in his fourth law of ecology: "Nature knows best." I shall first discuss the limitations of this law.

When left undisturbed, all environments tend toward an equilibrium state, called the climax or mature state by ecologists. Under equilibrium conditions, the wastes of nature are constantly being recycled in the ecosystem, which becomes thereby more or less self-perpetuating. In a natural forest, for example, acorns fall to the ground and are eaten by squirrels, which in turn may be eaten by foxes or other predators; the dead leaves and branches, the excrements of animals, are utilized by microbes, which return their constituents to the soil in the form of humus and mineral nutrients. More vegetation grows out of the recycled materials, thus assuring the maintenance of the ecosystem.

Nature Not Infallible

WHEN applied to such equilibrated systems, the phrase "nature knows best" is justified, but is in fact little more than a tautology. As used in this phrase, the word *nature* simply denotes a state of affairs spontaneously brought about by evolutionary adaptation resulting from feedbacks which generate a coherent system. There are no problems in undisturbed nature; there are only solutions, precisely because the equilibrium state is an adaptive state. But in a given area, there is usually more than one possible equilibrium state, and thus the *natural* solution is not necessarily the best or most interesting solution. As I shall illustrate later, the symbiotic interplay between man and nature has often generated ecosystems more diversified and interesting than those occurring in the state of wilderness.

What is surprising is not that natural environments are self-sustaining and generally appear efficient but, rather, that many of them constitute clumsy solutions to ecological problems, even when nature has not been disturbed by man or by cataclysms, and therefore could have been expected to reach the optimum ecological state.

That the wisdom of nature is often short-sighted is illustrated by the many disasters that repeatedly affect plants and animals in their undisturbed native habitats. The repeated population crashes among animal species such as lemmings, muskrats, or rabbits result from the defectiveness in the natural mechanisms which control population size. These crashes unquestionably constitute traumatic experiences for the animals, as indicated by the intense behavioral disturbances which often occur among them long before death. The crashes constitute, at best, clumsy ways of reestablishing an equilibrium between population size and local resources. Judging from the point of view of lemmings, muskrats, and rabbits—let alone human beings—only the most starry-eyed Penglossian optimist could claim that nature knows best how to achieve population control.

Incomplete Recycling

MOST surprising is the fact that even without environmental changes caused by human interference or accidental cataclysms, nature fails in many cases to complete the recycling processes which are considered the earmarks of ecological equilibrium. Examples of such failures are the accumulation of peat, coal, oil, shale, and other deposits of organic origin. These materials are largely derived from the

Dr. René J. Dubos presented this paper before the 139th Annual Meeting of the American Association for the Advancement of Science, Dec. 29, 1972, Washington, D.C. It was the fifth B. Y. Morrison Memorial Lecture, sponsored each year by USDA's Agricultural Research Service.

bodies of plants and other living things that have become chemically stabilized after undergoing only partial decomposition. The fact that they have accumulated in fantastic amounts implies, of course, that they have not been recycled. Paradoxically, man helps somewhat in the completion of the cycle when he burns peat, coal, or oil, because he thereby makes the carbon and minerals of these fuels once more available for plant growth. The trouble with this form of recycling is that the breakdown products of the fuels are so rapidly put back into circulation through air, water, and soil that they overload contemporary ecological systems.

The accumulation of guano provides another example of recycling failure on the part of nature. This material, now used as a fertilizer, consists of the excrements deposited by birds for millenia on certain islands and cliffs. For example, millions of sea birds use the Chincha Islands off the coast of Peru as a resting place and breeding ground; their droppings, accumulated through centuries, have formed layers of guano from 60 to 100 feet in thickness. Guano, being rich in nitrogen, phosphate, and potash, constitutes an ideal fertilizer, and its accumulation therefore represents a spectacular example of recycling failure. Here again, man completes the recycling process by collecting guano and transporting it to agricultural fields where it reenters the biological cycle in the form of plant nutrient.

Just as it is erroneous to claim that nature has no waste, so it is erroneous to claim that it has no junkyards. The science of paleontology is built on them. Admittedly, the accumulation of solid wastes in technological societies is evidence of a massive failure of recycling for which man is responsible. But this ecological failure is the expression of behavioral characteristics that have always existed in human nature. Like the great apes, primitive man was wasteful and careless of his wastes, and he has remained so throughout history.

The solid waste problem has become grave because we produce more wastes than in the past, and they are commonly of a chemical composition not found in natural ecosystems. Nature does not know how to deal with these situations that have no precedents in the evolutionary past. The solution to the problem of solid wastes, therefore, cannot be found in the ways of nature. It requires new technological methods and changes in the innate (natural) behavior of man.

The Human Touch

HAILSTORMS, droughts, hurricanes, earthquakes, volcanic eruptions are common enough to make it obvious that the natural world is not the best possible world; man is not responsible for these disasters, but he suffers from them as do other living things. Of greater interest, perhaps, is the fact that nature is incapable, by itself, of fully expressing the diversified potentialities of the earth. Many richnesses of nature are brought to light only in the regions that have been humanized: agricultural lands, gardens, and parks have to be created and maintained by human toil.

Until man intervened, much of the earth was covered with forests and marshes. There was grandeur in this seemingly endless green mantle, but it was a monotonous grandeur chiefly derived from its immensity and uniformity. The primeval forest almost concealed the underlying diversity of the earth. This diversity was revealed by man in the process of producing food and creating his civilizations. Since an extensive analysis of the creative transformations of the earth by man would be impossible here, I shall illustrate it with one single example, namely, that of the part of France where I was born.

Before human occupation, the Ile de France was a land without any notable characteristics. The hills have such low profiles that they would be of little interest without the venerable churches and clusters of houses that crown their summits. The rivers are sluggish and the ponds muddy, but their banks have been adapted to human use and their names have been celebrated so often in literature that they evoke the enchantment of peaceful rural scenes. The sky is rarely spectacular, but painters have created a rich spectrum of visual and emotional experiences from its soft luminosity.

Ever since the primeval forest was cleared by Neolithic settlers and medieval farmers, the province of the Ile de France has retained a humanized charm which transcends its natural endowments. To this day, its land has remained very fertile, even though much of it has been in continuous use for more than 2 thousand years. Far from being exhausted by intensive agriculture over such long periods of time, the land still supports a large population and a great variety of human settlements.

What I have just stated about the Ile de France is, of course, applicable to many other parts of the world. Ever since the beginning of the agricultural revolution during the Neolithic period, settlers and farmers have been engaged all over the world in a transformation of the wilderness. Their prodigious labors have progressively generated an astonishing diversity of manmade environments, which have constituted the settings for most of human life. A typical landscape consists of forested mountains and hills serving as a backdrop for pastures and arable lands, villages with their dwellings, their houses of worship, and their public buildings. People now refer to such a humanized landscape as "nature," even though most of its vegetation has been introduced by man and its environmental quality can be maintained only by individualized ecological management.

Manmade Problems

JUST as nature has not been capable by itself of giving full expression to its potential diversity, likewise it is not capable of maintaining manmade environments in a healthy state. Now that so much of the world has been humanized, environmental health depends to a very large extent on human care. Swampy areas must continually be drained, forests must be managed, the productivity of farmlands must be maintained by crop rotation, irrigation, fertilization, and destruction of weeds. From historical times, the Campagna Romana has been infested with mosquitoes and malaria every time men have lacked the stamina to control its marshes. Similarly, farmlands that have been economically productive and esthetically attractive for a thousand years are invaded by brush and weeds as soon as farmers neglect to cultivate them. The rapid degradation of abandoned gardens, farmlands, and pastures is evidence that humanized nature cannot long retain its quality without human care.

It is true that many ancient civilizations have ruined their environment and that a similar process is going on now in highly industrialized areas, but this is not inevitable. Intensive agriculture has been practiced for a thousand years in certain lands without decreasing their fertility or ruining their scenery. Man can create artificial environments from the wilderness and manage them in such a manner that they long remain ecologically stable, economically profitable, esthetically rewarding, and suited to his physical and mental health. The immense duration of certain manmade landscapes contributes a peculiar sense of tranquility to many parts of the Old World; it inspires confidence that mankind can act as steward of the earth for the sake of the future.

Lands could not remain fertile under intense cultivation unless managed according to sound ecological principles. In the past, these principles emerged empirically from practices that assured the maintenance of fairly high levels of humus in the soil. But scientific knowledge of soil composition and texture, of plant physiology, and of animal husbandry is providing a new basis for agricultural management. During the past century, the sound empirical practices of the past have been progressively replaced by more scientific ones, which include the use of artificial fertilizers and pesticides. Scientific agriculture has thus achieved enormous yields of plant and animal products. Furthermore, experimental studies have revealed that many types of lands can remain fertile for long periods of time without organic manure, provided they are continuously enriched with chemical fertilizers in amounts and compositions scientifically determined.

Energy and Efficiency

EFFICIENCY, however, cannot be measured only in terms of agricultural yields. Another criterion is the amount of energy (measured in calories) required for the production of a given amount of food. And when scientific agriculture is judged on this basis its efficiency is often found to be very low. Paradoxical as this may sound, there are many situations in which the modern farmer spends more industrial calories than the food calories he recovers in the form of food. His caloric expenditure consists chiefly of gasoline for powering his equipment and of electricity for producing chemical fertilizers and pesticides—let alone the caloric input required to irrigate the land and to manufacture tractors, trucks, and the multifarious kinds of machines used in modern farming.

Needless to say, modern civilizations would be inconceivable if the energy (calories) required by agriculture had to come from human muscles instead of from gasoline and electricity. But it is a fact, nevertheless, that if fossil fuels were to remain the most important source of power, the sheer size of the world population would make it impossible

to continue for long the energy deficit spending on which agriculture depends in prosperous industrialized countries. And there would be no hope of extending these practices to the developing countries, which constitute the largest part of the world.

No matter how the situation is rationalized, the present practices of scientific agriculture are possible only as long as cheap sources of energy are available. After the world supplies of fossil fuels have been exhausted, the modern farmer, like the modern technologist, will become ineffective unless energy derived from nuclear reactions or solar radiation can be supplied in immense amounts at low cost. Thus, the future of land management is intimately bound to the development of new sources of energy, as are all other aspects of human life.

Interplay of Man and Nature

OF the 70 to 100 billion people who have walked the surface of the earth since *Homo sapiens* acquired his biological identity, by very far the largest percentage have lived on the manmade lands that have been created since the agricultural revolution.

In every part of the world, the interplay between man and nature has commonly taken the form of a true symbiosis—namely a biological relationship which alters somewhat the two components of the system in a way that is beneficial to both. Such transformations, achieved through symbiosis, account in large part for the immense diversity of places on earth and for the fitness between man and environment so commonly observed in areas that have been settled and have remained stable for long periods of time.

Furthermore, the reciprocal transformations of man and environment have generated a variety of situations, each with its own human and environmental characteristics. For example, the agricultural techniques, social policies, and behavioral patterns in the various islands of the South Pacific are determined not only by geologic and climatic factors but even more by the cultural attitudes of the early settlers—Polynesians, Melanesians, or Indonesians—and then later of Western and Oriental people who colonized the islands. Cultural attitudes, more than natural conditions, are responsible for the profound differences between Fiji, Tahiti, and the Hawaiian islands. They were initially settled by different groups of people and, in addition to these early human influences, today exhibit the more recent influences respectively of their English, French, or American colonizers.

The shaping of nature by culture can be recognized in many other parts of the world. As the process of humanization of the earth continues, however, it will increasingly be influenced by the fact that most of the globe will soon be completely occupied and utilized. This colonization process began, of course, long before the days of modern technology. But the difference is that men now occupy and utilize all land areas except those that are too cold, too hot, too dry, too wet, too inaccessible or at too high an altitude for prolonged human habitation.

According to the United Nation's Food and Agricultural Organization, practically all the best lands are already farmed; future agricultural developments are more likely to result from intensification of management than from expansion into marginal lands. There probably will be some increase in forest utilization but, otherwise, land use will soon be stabilized. In fact, expansion into new lands has already come to an end in most developed countries and is likely to be completed within a very few decades in the rest of the world. A recent FAO report states the probable final date as 1985.

The U.N. Conference on the Human Environment came at a critical time in man's history. Now that the whole earth has been explored and occupied, the new problem is to manage its resources. Careful management need not mean stagnation. In many places, as already mentioned, the interplay between man and nature results in a creative symbiotic relationship that facilitates evolutionary changes. Man continuously tries to derive from nature new satisfactions that go beyond his elementary biological needs—and he thereby elicits the expression of some of nature's potentialities that would remain unrecognized without his efforts.

Call of the Wilderness

MAN has now succeeded in humanizing most of the earth's surface but, paradoxically, he is developing simultaneously a cult for wilderness. After having been for so long frightened by the primeval forest, he has come to realize that its eerie light evokes in him a mood of wonder that cannot be experienced in an orchard or a garden. Likewise, he recognizes in the vastness of the ocean and the endless ebb and flow of its waves a mystic quality not found in

humanized environments. His response to the thunderous silence of deep canyons, the solitude of high mountains, the luminosity of deserts is the expression of an aspect of his fundamental being that is still in resonance with cosmic events.

As mentioned earlier, nature is not always a good guide for the manipulation of the forces that affect the daily life of man; but undisturbed nature knows best—far better than ordinary human intelligence—how to make men aware of the cosmos and to create an atmosphere of harmony between him and the rest of creation.

Humanizing the earth thus implies much more than transforming the wilderness into agricultural lands, pleasure grounds, and healthy areas suitable for the growth of civilization. It also means preserving the kinds of wilderness where man can experience mysteries transcending his daily life, and also recapture direct awareness of the cosmic forces from which he emerged.

RESEARCH: BASIC VERSUS ORIENTED

In the long term, which contributes most to society: Basic research or mission-oriented research?

This is a difficult question because it is so hard to define contributions "in the long term." If we take indirect contributions into account, the discovery of differential calculus has contributed ultimately more to man's welfare than any mission-oriented research. If, however, we consider only direct and immediate effects, it is true that those resulting from mission-oriented big science are far greater than those of spontaneous, fundamental research.

Most mission-orientation imposed from the outside is directed toward a goal which can—and should—be attained. But some mission-oriented work is the result of individual motivation, the conviction of the scientist that he can solve a certain problem. As in individual research, this involves the element of luck. For example, among mission-oriented projects which have contributed to human welfare, that of Borlaug may be counted particularly successful. Yet even Borlaug, though I did not ask him directly, would admit that chance played a role in his discovery of the hybrid wheat which has proved to be so effective in combating food shortages.

—From an interview with Eugene P. Wigner, Hungarian-born mathematical physicist, who was cowinner in 1963 of the Nobel Prize in Physics, in *Impact of Science on Society,* vol. 22, No. 4, a journal of UNESCO, Paris.

FORUM

A RATIONALE FOR RESEARCH INSTITUTES

SCIENTIFIC inquiry has become a political necessity. State and Federal governments alike now recognize research as an important instrument for achieving political aims and objectives. Accordingly, these governments have become buyers of research and have been making available to institutions of higher learning large sums of money for the performance of research services. Academic institutions, in turn, have found it difficult to adjust to this new research demand.

So formidable is the adjustment problem that some academic administrators advocate a retreat from the market entirely. Typically these administrators hold to the tenets that research, if it is undertaken at all, must be kept a personal matter, that the prime mission of the university is instruction, and that the university community cannot supply the research needed without being distorted or controlled.

Obligation to Respond

FORTUNATELY, the view still prevails in some quarters that academic institutions have a social obligation to respond to the needs of government and to accept responsibilities which lie outside their own immediate interests and ambitions. Where the will to oblige is weak, there are those who look at the matter from a practical point of view and conclude that public claims against them must be satisfied or public support for their institutions will decline. As expressed by Dean Daniel Alpert of the University of Illinois at a meeting of the Council of Graduate Schools in 1969: "I believe the university *must* address itself to the major problems posed by society not because society will not survive if we fail to come up with solutions, but because the university will not survive if we cannot persuade our students and the public that we are seeking to understand such problems."

The reality of the situation is that universities can respond to modern demands of government, just as they have responded in the past to the demands of industry and the professions. Many universities today are structured not alone to advance the basic arts and sciences but to better serve such private sectors of society as agriculture, mining, engineering, medicine, and law. In an age of increasing governmental complexity, these universities also can be structured to better serve the needs of governmental agencies. Providing assistance to the private sector of the economy has not undermined the aims and ideals of academia. Providing assistance to the public sector need not do so either.

Structural rigidity appears to be one of the reasons why academic institutions have difficulty responding to modern research demands. In part, this difficulty stems from a university structure that is discipline oriented rather than program oriented. Most university departments carry out many programs or parts of programs, but are organized around a discipline. Allocation of departmental resources among these functions tends to be dispersed among many individuals, including the department chairman and faculty members. More difficult is the fact that the allocation of resources among departmental func-

tions frequently tends to be a series of unconscious acts, decisions by default. While no one intends deception or subterfuge, the end result can be no less damaging.

Overcoming Rigidity

STUDIES recently completed at the Pennsylvania State University highlight the special character and purpose of centers and institutes in overcoming structural rigidity. Special attention is given to State water resource research institutes. These institutes were established in each of the States—generally at the land grant university—under provision of the Water Resources Research Act of 1964. The units play an important part in university life because they enable universities to attack contemporary problems, to strengthen their accountability, and to gain flexibility in ways not normally possible in the conventional academic department.

Universities are currently under great pressure to increase productivity. Persistent attempts, for example, have been made to develop and apply program planning budgeting systems in higher education. The reasons for such pressures are complex and reflect the increased cost of higher education, the public consciousness of the growing tax dollars required by all levels of education, and a recognition by universities themselves of their inability to manage academic programs and resources as effectively as they must.

Institutes and centers are particularly viable in that they can forthrightly meet these challenges. They tend to have a direct relationship between the functions they perform and their organizational structures. Water resource research institutes, for example, know what their mission is! They are accustomed to reporting periodically to Washington authorities and other sponsors on what they are accomplishing. Because their mission is specific and they are "setup" to accomplish it, there is little wastage in their production efforts. Relevant problems can be identified, research objectives can be clearly formulated, and findings can be easily specified.

Because institutes are far more self-contained in their production efforts, dollar costs of production are more readily obtained and are more highly valid than many other university cost data. Institutes often take care of their own accounting matters, publication processing, equipment repair, and so on and in this respect are directly accountable for almost all of their efforts. Institute budgets tend to be related directly to programs, and tend to fluctuate in response to program volume. Traditional departmental budgets, on the other hand, tend to be comparatively stable, and incremental.

No Monolithic System

THE Pennsylvania State University study of water resource research institutes turned up one other significant finding. Despite their common mission, institutes show great variability in their organization, operation, and activity. They do not form a uniform, monolithic system. This is important. It is the distinctiveness of institutes and centers that makes them valuable additions to the university scene, and it is this same uniqueness that must be preserved and strengthened in the years ahead if water resource research institutes and other institutes and centers in American universities are to fulfill their full promise to universities and to the society they serve. There is no evidence that the Federal bureaucracy which sponsors them forces them into one mold or pattern.

All of this is to suggest that institutes and centers are quite different from academic departments, and because of this difference they make a genuine contribution to the vitality of university organizational structure. On the basis of significant research findings it can be concluded that institutes and centers, and particularly the water resource research institutes, are able to demonstrate productivity, that they can pass the test of accountability, and, equally significant, they can be sufficiently diverse to be adaptable to specific situations in the States and institutions in which they are located.

G. Lester Anderson, *Director, Center for Study of Higher Education.*

John C. Frey, *Director, Institute of Research on Land and Water Resources.*

Stanley O. Ikenberry, *Senior Vice President of University Development and Relations.*

William M. Swope, *Research Assistant, Institute of Research on Land and Water Resources, Pennsylvania State University.*

SCIENCE NOTES

FOOD LEGUMES RESEARCH

THE development of high-yielding varieties and the improvement of nutritional qualities of food legumes were seen as high priority items at a symposium called by the United Nations Protein Advisory Group.

"The Green Revolution will not be complete until similar achievements are accomplished with food legumes as has been done with cereals," the participants in the symposium said in their report.

Norman Borlaug, Nobel Peace Prize winner for his role in wheat development, said at the meeting: "If we take advantage of the experience gained in cereal improvement and use the same interdisciplinary and team approach, similar results can be obtained not in 25 but in 10 years."

Dry beans, chick peas, cowpeas, peanuts, and soybeans are some of the better known food legumes with a high protein content that were discussed. In some developing countries, such products already fill the nutritional role which milk, meat, and fish provide in prosperous countries. An increase in the yield potential of legumes and improvement in their protein content, their digestibility, and other nutritional qualities is considered vital.

BIODEGRADABLE PLASTICS

Scientists at the University of Aston, Birmingham, England, have developed an additive that makes plastics decompose after exposure to bright sunlight. The chemical is an organic complex of iron that sensitizes most plastics to photo-oxidation in sunlight. The breakdown is irreversible and continues even after the plastic is buried as in landfill.—Journal of Environmental Health, vol. 35, No. 3.

CATTLE FEEDING TRIALS

OHIO feeding trials confirm recently announced Iowa research that indicates cattlemen may not need to feed supplemental protein to feeder calves after an initial feeding period.

Ninety steer calves were used to determine effects of the length of supplemental protein feeding by comparing feeding of protein for the first 56 days, the first 112 days, or continuously for the full feeding period. Cattle were on a corn-corn silage ration.

Feedlot performances and carcass quality were essentially the same whether steers were fed supplemental protein for only the first 56 or 112 days of the feeding period or fed supplemental protein all the way to market weight.

Minerals, vitamins, antibiotics, and hormone supplementation were maintained—only protein was withdrawn. Corn and corn silage fed to the cattle had normal protein levels.—*Department of Animal Science, Ohio Agricultural Research and Development Center.*

STABILIZING SILTY SOILS

A technique has been developed by scientists in Belgium for stabilizing silt with a moisture content between 15 and 25 percent by the addition of quicklime. Rapid flocculation occurs and the lime takes the place of alkalis, thus eliminating the soil absorptive capacity for water.—Ceres, FAO Review, vol. 5, No. 6.

DEVELOPING LESS THIRSTY PLANTS

IT IS estimated that over 1,000 pounds of water are required to produce 1 pound of bread and that over 23,000 pounds of water are required by a steer and the forage it eats in the production of 1 pound of beef.

Two University of Arizona agronomists, A.K. Dobrenz and M.A. Massengale, have aimed their research at finding plants which can produce more dry matter while using less water. They reported some of their findings at the annual meeting of the American Society of Agronomy in Miami Beach, October 29–November 3, 1972.

The process of transpiration by which plants lose tremendous quantities of water has often been called a necessary evil. Dobrenz and Massengale applied several antitranspirant and growth regulator chemicals and found that Gibberallic acid did increase the efficiency of water use. Leaf area reduction can also be utilized to improve the water requirement of

cereal grains. This involves the removal of the basal leaves on the plant during the stage of maturation, thus reducing the transpiring area of plants.

Dobrenz reported that the total amount of water applied to alfalfa was cut by 40 percent when high-producing adapted cultivars were grown and monitoring of the available soil moisture was used for application of irrigation water.

Numerous plant characteristics were observed in an attempt to find a feature which can be utilized by plant breeders to select more water-use efficiency plants. The amount of cutin on the leaves of certain grass species is significantly related to the water needs of those plants and appears to be an effective technique for isolating efficient lines. Various anatomical features of the plant roots also appear to be associated with efficient use of water.

SALMONELLOSIS VICTIMS

An estimated 2 million Americans—or one person out of 100—each year suffer from salmonellosis. Though often mistaken for a 24-hour virus because of symptoms (headache, fever, stomach cramps, diarrhea, and vomiting), salmonellosis is an infection of the stomach and intestines caused by salmonella germs which are sometimes present in such foods as fresh meat, poultry, and fish.—Journal of American Dietetic Association, vol. 62, No. 7.

IMPROVING STRAW AS FEED

ANIMAL scientists at Oregon State University are improving digestibility of straw by using hydroxides to break down lignin, making it more usable for ruminants.

Tests with treated pelleted straw show that, although an acceptable feed from the standpoint of animal performance, the costs of treating, drying, and pelleting are too great to be competitive. Initial tests with straw silage show that this form of feed is more promising because there are no drying and pelleting costs and natural fermentation in the ensiling process buffers the hydroxide.

Silage additives and their amounts are being determined. Digestion trials with sheep are underway and will be followed with feeding trials on beef heifers. The goal is to put 1½ pounds a day on a 500-pound heifer. If successful, the researchers think straw silage will compare favorably with alfalfa hay on a cost-gain basis.—*Oregon's Agricultural Progress,* fall 1972.

BASIC RESEARCH AND KNOWLEDGE OF THE EARTH

The relation of the earth to human affairs requires a broad understanding of earth processes and systems. It is not possible to know in advance what particular set of data or observations about the earth will be relevant to the solution of future environmental issues. Even with many current environmental problems we lack the critical data necesssary to evaluate adequately the impact of our existing interactions with the natural environment. Consequently, basic research about the earth must continue and flourish if it is to provide the essential framework of observations, concepts, and principles upon which the environmental impact studies can be soundly based.

The very nature of basic research is such that it will not always, or even usually, lead to discoveries that are immediately applicable. There is, of course, a kind of serendipity that operates in basic research, in which seemingly "useless" or "irrelevant" scientific inquiry turns out to have direct and important application.

Basic research should include inquiry not only into the nature of earth processes but also into the history of those processes; for the earth's present condition is the result of a long and varied evolutionary development. If we are to understand how an earth system operates, we may need to know both the present processes at work and how that system will change in the future—with or without human intervention.

—From "The Earth and Human Affairs," a publication of the Committee on Geological Sciences, Division of Earth Sciences, National Research Council-National Academy of Sciences.

THE AUTHORS

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R. J. Dubos ("Humanizing The Earth") was associated with the Rockefeller University for 44 years before retiring in 1971. Dr. Dubos continues to write and lecture throughout the United States and abroad. He is noted as an eminent microbiologist and experimental pathologist, has achieved distinction as a scientific humanist with such books as "Man Adapting;" "Man, Medicine and Environment;" "So Human an Animal" (which won a Pulitzer Prize in 1969); "Reason Awake: Science for Man;" and, "A God Within," and recently coauthored with Barbara Ward "Only One Earth." After graduating from the Institute Nationale Agronomique in Paris, he worked for 2 years at the Internationale Institute of Agriculture in Rome. In 1924 he came to the United States and received his Ph. D. from Rutgers University in 1927. Except for 2 years at Harvard's Medical School, he has worked for the Rockefeller Institute. Dr. Dubos has received numerous honorary science degrees, awards, and medals from institutions worldwide.

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